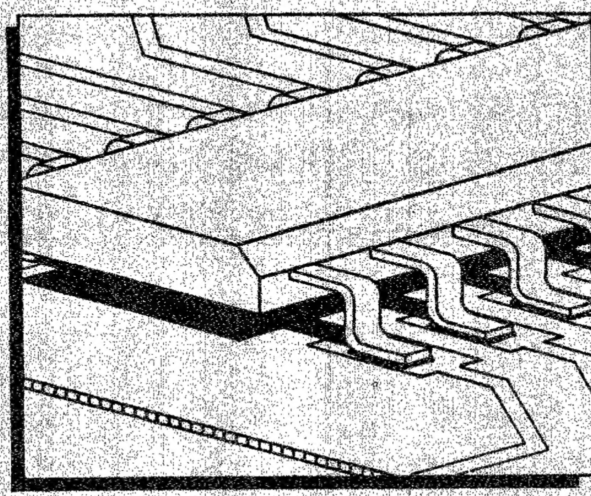
Reliable Application of Plastic Encapsulated Microcircuits

RAC Parts Selection, Application and Control Series



Reliability Analysis Center

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Reliable Application of Plastic Encapsulated Microcircuits

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This report summarizes and analyzes the issues relating to Plastic Encapsulated Microcircuit (PEM) Reliability. Included is: 1) discussion of current research efforts within the government and industry, 2) failure modes and mechanisms associated with PEMs, 3) test data on PEMs subjected to HAST, life test, Autoclave, high temperature storage, 85°C/85%RH tests, 4) field reliability data, 5) analysis of both test data and field data, 6) a reliability assessment model derived from the data and 7) conclusions regarding the selection and applications of PEMs.

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PREFACE

Recent trends in military procurement practices have led to the increased usage of Commercial-Off-The-Shelf (COTS) equipment and components. This has resulted in the increased consideration of Plastic Encapsulated Microcircuits (PEMs) for use in many military applications. Proponents of their use argue that they are more available, lighter weight, and lower cost. Critics argue that their reliability in harsh environments is uncertain, that there is a lack of quality/reliability assurance procedures and that there is insufficient empirical data to warrant their use.

While early usage of PEMs in the 1970's resulted in poor reliability performance, it is generally recognized that their reliability has since increased orders of magnitude. However, even with this improvement, many manufacturers desire convincing data that indicates that their reliability and lifetimes are adequate in harsh environments.

In an attempt to provide quantitative information as to whether PEMs can be used reliably in harsh environments for long design lives, the RAC initiated a study in which the intent was to collect and analyze as much empirical data as possible. Data was collected on PEMs from a variety of sources in order to quantify their reliability under numerous test and field use conditions. A reliability assessment model has been developed.

The authors would like to acknowledge James Reilly, Duane Gilmour and Dan Fayette of Rome Laboratory and Edward Hakim of Army Research Laboratory for their support and contributions to this publication. Edward Aoki, of Hewlett Packard, is thanked for his contribution to the references section of this report.

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1.0 INTRODUCTION

In today's sophisticated electronics workplace, reliability/quality, availability and cost are important considerations in the selection of components for products intended for the telecommunications, computer, automotive and military markets. The selection of hermetic or plastic encapsulated semiconductor packaging, which is still an important factor which must be assessed, can have a significant effect on the aforementioned considerations. The differences in these packaging approaches are illustrated in Figure 1.0-1. The significant amount of data and information that is provided and discussed in this report will assist your evaluation of the reliability and quality of plastic encapsulated microcircuits (PEMs).

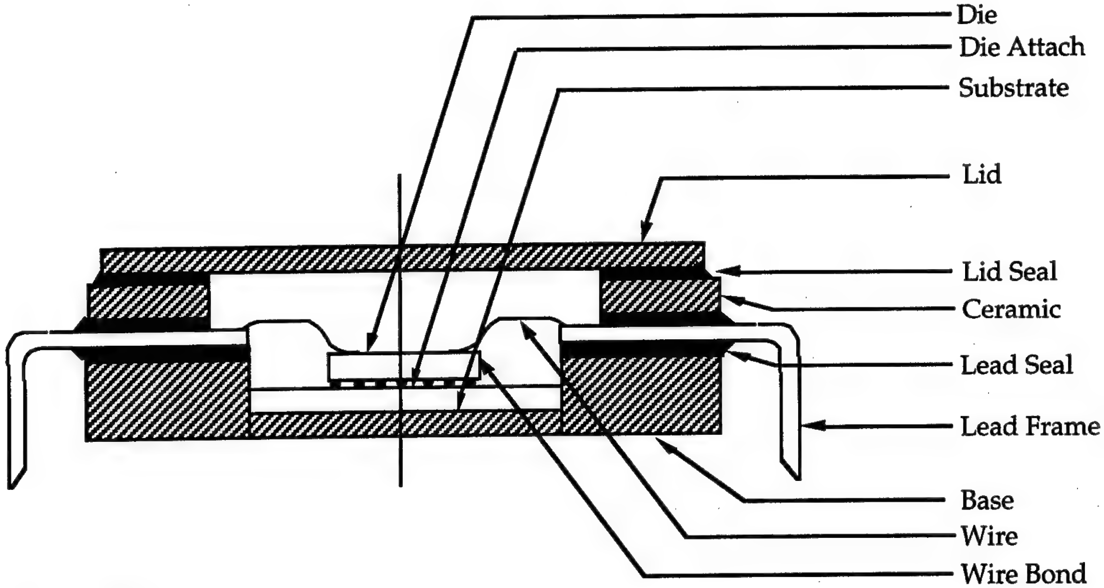
A PEM uses organic packaging material, either transfer molded or coated, for environmental protection. This material is in direct contact with the semiconductor element or an inorganic barrier layer. This is in contrast to metal or ceramic packaging, which has a hermetically sealed cavity and no active element or organic barrier interface with the packaging material. The vast majority of PEM usage has been in commercial, telecommunication, automotive and industrial applications. Military usage has been generally limited to high shock (munitions) and Nondevelopmental Items (NDI) or Commercial Off-The-Shelf (COTS) applications.

The major advantages that can be gained from the use of PEMs:

- Greater availability (especially surface mount packaging)
- Lighter weight
- Lower cost (high volume procurement)

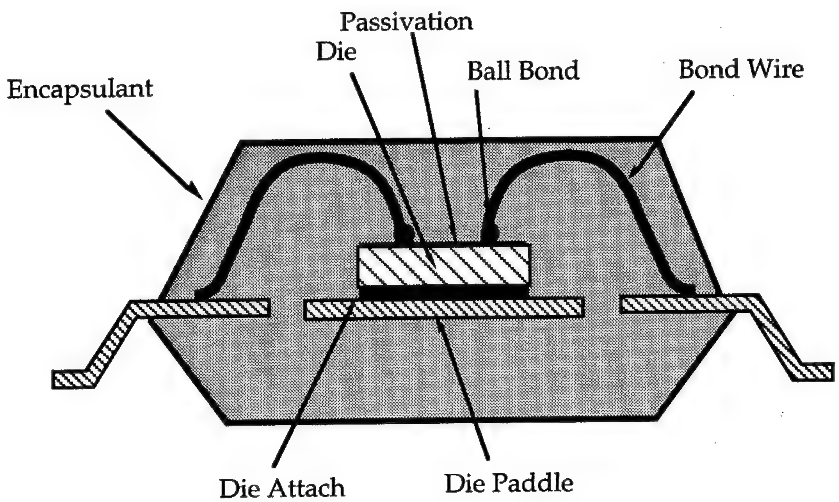
Concerns associated with increased PEM usage, especially in military applications, include:

- Uncertainty regarding their long term reliability in harsh environments
- Lack of industry standard reliability/quality assurance procedures
- Insufficient military environment reliability data (operating and storage)
- Existing military Original Equipment Manufacturer (OEM) procurement expertise



CERAMICS:

- Single Base and Lid material
- Single Lid Seal material
- Single Substrate
- Single Lead Frame
- Single Die Attach material
- Single Wire material (Al)
- Mono metallic interface (Al to Al)
- Die Final passivation scratch; Ionic protection
- Single External lead finish
- Hermetic Cavity



PEMS:

- Multiple Encapsulants (Formulations) (High, Low: Stress; Ionic; Particle size; TCE Flame retardants; Glass transition, etc.
- Multiple Lead frame materials (Cu, Alloy 42)
- Multiple Die Attach materials (Formulations)
- Multiple wire materials (Mostly Au; Al, Cu)
- Bi metallic interface (Al to Au)
- Die Final Passivation scratch, Ionic, Corrosion protection, Interface matching required
- Single External lead finish
- Non Hermetic Bulk (Interfaces important)

FIGURE 1.0-1: THE DIFFERENCES BETWEEN HERMETIC (CERAMIC) AND PLASTIC PACKAGING

The concern over the lack of industry standard R&QA procedures is diminishing because of the following specification activity:

- Automotive Electronics Council (Chrysler, Delco, Ford) CDF-AEC-Q100-Rev. A, "Stress Test Qualification for Automotive Grade Integrated Circuits" (19 May 1995)
- MIL-PRF-38535 "Integrated Circuits (Microcircuits) Manufacturing, General Specification For", which includes provisions for PEMs
- JEDEC Standard 26 "Plastic Packages for Use in Rugged Applications" (being prepared)

Usage of early PEM's (1970's) was discouraged because of high failure rates. Table 1.0-1 summarizes predominant failure mechanisms and causes experienced in those devices. However, major improvements have been made in the fabrication of PEMs. The following lists some of the processes/materials/testing procedures that have been improved.

- Materials - increased epoxy molding compound (e.g., resin) purity
- Material attributes - enhanced CTE, glass transition temperature, fracture toughness, moisture desorption, adhesion, viscosity, mold release, appearance
- Lead frame design
- Die coatings - high quality device passivation (i.e., silicon nitride)
- Die design (i.e., metal layout)
- Material characteristics - reduced ionic contaminants such as chloride and other halides, flame retardant stability, and ion scavengers
- Fabrication equipment
- Testing procedures - Highly Accelerated Stress Testing (HAST), autoclave, moisture absorbance, C-Mode Scanning Acoustic Microscopy (C-SAM) and dye penetration testing

TABLE 1.0-1: PEM FAILURE MODE/MECHANISMS (CIRCA 1970's)

Failure	Cause
Wire bond intermittency/lifting	Coefficient of thermal expansion (CTE) differences
Wire/metallization corrosion	Moisture/contamination
Voiding/poor adhesion	Processing/materials
Data/soft errors	Alpha particles (filler material)

Recent data show that the failure rate of plastic packages has decreased from about 100 failures per million device hours in the 70's to those shown in Table 1.0-2.

TABLE 1.0-2: AVERAGE EARLY LIFE FAILURE RATES OF PEMS

Application	Failure/10^6 Hours
Computer/Test Equipment	0.0007
Commercial Aircraft	0.04 - .07
Automotive	0.1 - 0.7

Today the most popular molding compound is based on epoxy novolac resin. The basic composition contains, by weight, 15-30% epoxy resin and hardeners; 60-80% fillers; 1-7% pigment, mold release, coupling agent and stress absorbers; 1-5% flame retardant; and 1-2% catalyst. Reduction of chloride and other halides in the basic epoxy composition, stable flame retardants and ion scavengers have essentially eliminated aluminum wire and chip metallization corrosion problems. Single bit loss and soft errors have been reduced through reduction of alpha emitting elements and by barrier coating of the integrated circuit (IC) die.

Delamination or "popcorning" associated with surface mount technology (SMT) using various soldering techniques is understood and can be controlled. Techniques used include baking the finished part and sealing it within an airtight plastic bag with a desiccant to reduce moisture levels. A second method that has proven successful is controlling temperature ramp change rates during soldering. At the device level, delamination effects can be reduced by perforating leadframes, decreasing filler particle size, and stamping lead frames to eliminate burr formation sites that contribute to stress concentration.

PEMs are currently being used in harsh environments, such as automotive under-hood applications and commercial avionics systems. The mechanical

ruggedness of plastic packaged devices makes them attractive in high shock and vibration applications that can damage ceramic packages.

To ensure PEM reliability, it is important to carefully review each potential vendor's manufacturing process and reliability test results. Additionally, while PEM's are typically available and guaranteed by the vendor to perform over the commercial temperature range of 0-70°C, to vendor electrical parameters, the industry has had success with the use of these devices at greater temperature extremes. However, to ensure performance it is necessary for each OEM to not only certify each vendor, but also to verify that each device will satisfy its intended application. For example, temperature can affect device parameter limits (e.g., speed) or reliability (e.g., excessive current density).

Some items that have been proven to enhance reliability that can be used in evaluating the integrity of a supplier of plastic parts include, but are not limited to:

- reduced phosphorus levels in passivation
- dual layer passivation to ensure passivation integrity
- perforated lead frames
- benign (non-ionic) cleaning of lead frames after molding
- use of copper lead frames
- reduced stress trim and form
- corrosion resistant mold compounds
- nitride passivation
- control/elimination of ionic contamination
- comprehensive reliability program

Today there is general acknowledgment that there have been significant improvements in plastic encapsulated devices. Although their failure mechanisms have not been totally eliminated, they have been reduced by orders of magnitude.

Interest in the use of PEMs in commercial and industrial products for industrial and military applications is rising. The Army's advocacy has resulted in the proposed use of PEMs in several Army systems, which complements their current use in munitions. Both Army and Navy organizations have sponsored workshops to solicit active discussion of PEMs in all environments. The Army released MIL-HDBK-179 (ER) "Microcircuit Application Guide Book", dated 25 October 1993, to provide guidance for the use of PEMs. The A version of this document, dated 20 July 1995, is now approved for use by all departments and

agencies of the DoD for guidance. The Air Force is actively involved in evaluating PEMs and developing test and procurement procedures to ensure their quality and reliability when procured in accordance with "best commercial practices." These subjects, as well as other relevant topics, are addressed in this report.

"Best commercial practice" is an ambiguous phrase that is used to describe the procurement of components, including PEMs. Each semiconductor company has in place an established procedure to supply and warranty PEMs that operate over the temperature range of 0 - 70°C to their specified performance levels. In addition, users have established procedures to complement "best commercial practice", such as vendor assessment and selection, testing/reliability monitoring and device design. This is not a criticism of vendor procedures, but indicates that the commercial/industrial use of PEMs includes supplier audits, data analysis, device robustness assessment and testing in addition to suppliers' standard processing to establish a baseline. However, when a relationship like this exists (i.e., user/vendor alliance demonstrates acceptable quality levels), features such as ship to stock, and on-line reliability monitoring of vendor testing/processing are becoming common.

On 29 June 1994, Secretary of Defense William Perry signed a memorandum dealing with Military Specifications and Standards labeled "A New Way of Doing Business". Basically, the memo directs the Department of Defense (DoD) to increase its use of "best commercial practices" and products. This would be accomplished by (1) requiring the use of performance specifications and Non-Government Standards (NGS) instead of military unique specifications and standards; (2) requiring waivers to justify the use of military specifications and standards for DoD acquisition programs; (3) emphasizing the use of process controls in lieu of government oversight and testing requirements; and (4) restricting excessive document tiering and referencing. This memorandum was an outgrowth of the Report of the Process Action Team on Military Specifications and Standards, April 1994, led by Ms. Colleen Preston, Office of the Undersecretary of Defense for Acquisition & Technology. In general, the intent of this new direction in DoD acquisition is to meet future needs by increased access to commercial state-of-the-art technology and adoption of business process characteristics indicative of a world class supplier. In addition, integration of commercial and military development and manufacturing facilities are endorsed, thus leading to an expanded industrial base

capable of meeting defense needs at lower cost. This goal can only be accomplished by eliminating or modifying the military unique acquisition requirements.

Included in this new approach to military system procurement is the use of commercial parts including PEMs and the use of commercial manufacturing facilities and processes. The guidance within this report is intended to assist the implementation of PEMs into military systems/equipment.

The theme of a previous Reliability Analysis Center (RAC) report "Plastic Microcircuit Packages: A Technology Review", was to indicate that measurable improvements in their quality and reliability were becoming evident, and that significant user interest, whether they be automotive, commercial, industrial or military customers, had been documented. Also, the report provided information to help answer the question "Why does the military limit the use of plastic packaged devices?" At that time, answers to this question included:

- a lack of usage data from severe/harsh and storage environments
- no definitive test/procurement procedures
- the lack of a industry/government working relationship similar to that which exists for hermetic packaging

Since the publication of the RAC document in 1992, numerous programs, workshops, meetings and journals have provided additional information that should provide confidence in the wider utilization of PEMs. To further assist this wider utilization, the RAC implemented the Information Management Program on Advanced Component Technologies (IMPACT) program to enhance its data collection effort specifically for plastic packaged devices. Information was solicited on plastic packaged monolithic, GaAs and hybrid microcircuits and multichip modules, including failure rates and failure modes/mechanisms. Special emphasis was placed on:

- Air Force, Army, and Navy R&D organizations (i.e., Rome Laboratory, Naval Surface Warfare Center and Army Research Laboratory) who are in the forefront of new technology and their application in military systems.
- Component manufacturers/test houses to collect results of burn-in and life testing on the latest technologies. Device test data has been found to be an important data source due to the time delay of fielding equipment, non-

existent or undependable data tracking and the prohibitive cost of collecting, evaluating and summarizing data.

- Component users, to collect system data from all environments (i.e., automotive, telecommunications, computer, military and commercial OEMs). This typically results in 1 year warranty data.

- Technical Interchanges - RAC participates in many forums (i.e., RwoH Programs, SHARP and microelectronic quality workshops, IRPS) which are major educational exchanges for component technologies and systems.

All new information and data collected from the IMPACT initiative is housed in existing RAC databases. Quantitative data has become part of the RAC component databases that presently include failure rate, time-to-failure, failure mode/mechanism and electrostatic discharge susceptibility data. Qualitative information has become part of RAC's bibliographic database.

This program has led to the collection of a significant amount of data from various environments/sources. Table 1.0-3 lists the sources and the type of data that was collected in the IMPACT effort. While the companies listed in this table submitted data to RAC as part of the IMPACT data collection initiative, there already existed a significant amount of PEM data in the RAC database. All data analysis and modeling efforts were based on all available RAC data which includes but was not limited to data from the listed organizations.

The results of the IMPACT data collection effort includes information on device reliability and burn-in/life testing from vendors, test houses and government test activities. Many variations of data from commercial airplane and automotive environments; specification and test method activities and device test and evaluation programs from both commercial and government activities are discussed.

Due to the success of this study in collecting empirical data from a variety of sources it was now possible to quantify the reliability of PEMs under a variety of test and field usage. As a result, major emphasis was placed on developing a PEM reliability assessment model. Collected data was summarized and analyzed to determine its significance and impact on PEM reliability. The model form is based on the contribution of defects and identified failure modes/mechanisms. Model

application is flexible, allowing the use of user/vendor existing data, or the default values derived from the RAC database.

TABLE 1.0-3: DATA SOURCES

Company	Type Of Data
AT&T - Component Evaluation Technology Center (CETC)	Component Test and Evaluation
Delco	Automotive User
PAR	Commercial User(Point of Sales Equipment)
Honeywell	Commercial User (Commercial Avionics)
TI	Semiconductor Vendor
Signetics	Semiconductor Vendor
Intel	Semiconductor Vendor
TriQuint	Semiconductor Vendor (GaAs)
Alliant Tech Systems	Military OEM (Munitions, Fuzes)
Hewlett Packard	Commercial OEM
Beckman Industrial	Hybrid Microcircuit Vendor
Catalyst Semiconductor	Semiconductor Vendor
Bofors Missiles	Military OEM
Eldec Corp.	Commercial/Military OEM
Ericsson Telecom	Telecommunications
Hughes Aircraft	Military OEM
Group Technology Corp.	Military OEM
National Semiconductor	Semiconductor Vendor
Dow Corning	Materials Vendor
Unitrode	Semiconductor Vendor
RelTech	Government
General Dynamics	Military OEM
Naval Surface Warfare Center Crane (NSWC)	Government
US Army Research Labs	Government
Rome Laboratory	Government

Additionally, responses from solicited CRTA PEM subscribers indicated the need for a destructive physical analysis (DPA) procedure and a recommended plastic decapsulation procedure, both of which have been included as part of this report.

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2.0 VISIBILITY WITHIN THE MILITARY

The advent of acquisition reform resulting from the Perry memorandum has fostered a resurgence in the use, test and evaluation of PEMs. Consequently, the military has taken an active role in leading the discussion of PEM use in various environments encompassing both positive and negative viewpoints. Additionally, reliability studies to evaluate PEMs in the military environment have been undertaken. The decision of whether or not to use PEMs appears to be evolving from a yes or no answer to one of PEM vendor assessment, and technology evaluation for performance and environmental application. In other words, how can a PEM vendor and device be selected that will satisfy the intended application requirements. The following discussions summarize DoD, DLA and NASA activities concerning workshops, specifications, and program activities which can be used to aid in this decision.

2.1 SHARP Workshops

The Standard Hardware Acquisition and Reliability Program (SHARP) sponsored their second and third annual workshops, entitled "Commercial and Plastic Components in Military Applications", in Indianapolis, IN, during November, 1993 and 1994. The 2nd annual Workshop Proceedings, published in two volumes, included 15 papers directly relevant to the subject matter, as illustrated in Appendix B-1 listing of the agenda, the presenters and their affiliation.

The third annual workshop proceedings included 17 papers directly relevant to the subject matter, as illustrated in the Appendix B-2 listing of the agenda, the presenters and their affiliation.

2.2 Microelectronics Quality Workshop

The annual Advanced Microelectronics Qualification/Reliability Workshop, sponsored by ARPA and the Army Research Laboratory, was held in Denver, CO in August, 1993, in Newton, MA during August, 1994 and in Newport Beach, CA during August, 1995. The 1993 Workshop Proceedings included several presentations (among the 38 total) relevant to the study of using plastic packaged

microcircuits in military environments, as illustrated in the Appendix B-3 listing of the papers, the presenters and their affiliation.

Many of the papers presented at the 1994 workshop discuss the application of PEMs in military systems and their procurement using best commercial practices. These papers are listed in Appendix B-4. The focus of the 1995 workshop concerning PEMs included issues associated with testing, qualification and use. The papers from this workshop are listed in Appendix B-5.

2.3 PEM Specifications

Two specifications are being considered for use in the test and procurement of PEMs. They are described in paragraph 2.3.1 and 2.3.2.

2.3.1 MIL-PRF-38535 Integrated Circuits (Microcircuits) Manufacturing General Specification

This is the first military microcircuit specification to be considered a performance specification under acquisition reform. As a result, the DoD can cite it for use in military programs. Table 2.3-1 identifies PEM tests/monitors included in MIL-PRF-38535.

Table 2.3-2 identifies key package characteristics for which testing should be addressed on each Qualified Manufacturers List (QML) package technology style.

It is pointed out that the QML system is predicated on a total quality approach, including vendor validation and device/package evaluation and testing. Acceptance or rejection of devices or technology can not be made on the passing or failing of a single test.

TABLE 2.3-1: TESTS/MONITORS FOR PLASTIC PACKAGES

Test/Monitor	MIL-STD-883 Test Method or Industry Standard
1. Wafer acceptance	TRB plan (see appendix H)
2. Internal visual	TM 2010 or per manufacturers internal procedures
3. Temperature cycling/thermal shock	TM 1010/TM 1011
4. Resistance to solvents	TM 2015
5. Bond strength	TM 2011
6. Ball shear	ASTM F 1269
7. Solderability	TM 2003
8. Die shear or stud pull	TM 2019 or TM 2027
9. Steady-state life test endpoint electricals	TM 1005 per device specification
10. Physical dimensions	TM 2016
11. Lead integrity	TM 2004
12. Inspection for delamination	TM 1034 (Dye Penetrate), cross-sectioning, CSAM etc.
13. HAST	50 hours, 130°C, 85% RH 2/
14. Autoclave	JESD 22-A102 (no bias) 2 ATM., 121°C
15. Salt atmosphere	TM 1009
16. Adhesion to lead finish	TM 2025
17. Interim pre burn-in electricals	Per device specification
18. Burn-in test	TM 1015, 160 hours at 125°C or per manufacturers QM plan
19. Interim post burn-in electricals	Per device specification
20. Percent defective allowable (PDA) or alternate procedure for lot acceptance	1% PDA or per manufacturers QM plan
21. Final electrical tests (see Table III for definition of subgroups) a. static b. dynamic c. functional d. switching	Per device specification
22. External visual	TM 2009 or JESD 22-B101 or manufacturers internal procedures

1/. Test methods are listed herein to give the manufacturer an available method to use. Alternate procedures and test methods may be used. Monitor frequency and sample plan should be in accordance with manufacturer's QM plan.

2/. An alternate process monitor may be used (e.g., 85°C/85% RH).

TABLE 2.3-2: PACKAGE TECHNOLOGY STYLE CHARACTERIZATION TESTING FOR PLASTIC PACKAGE

Group Number	Process	Test	MIL-STD-883 Test Method or Industry Standard
1	Dimensions	Physical Dimension	TM 2016 1/
2	Resistance to moisture	Preconditioning Electrical Testing Biased HAST (500 hours, 130°C, 85% RH) Endpoint Electricals	2/ per device specification JESD 22-A110 3/ per device specification
3	Susceptibility to leakage and corrosion	Salt Atmosphere	TM 1009
4	Susceptibility to leakage and corrosion	Autoclave (no bias) (pressure pot) 2 ATM., 121°C	JESD 22-A102 (data to be provided for 96 hours and 168 hours)
5	Leads	Lead integrity	TM 2004, Condition A, B2 or D
6	Susceptibility to moisture induced cracking at reflow soldering for surface mount and applicable through hole packages	Moisture intake Reflow simulation Inspection for delamination and cracks	168 hours at 85°C/85% RH or bake + minimum guaranteed time at 30°C/60% RH Vapor phase (219°C maximum). Cross-section at 1000x, ultrasonic (CSAM) etc.
7	Safety	Flammability	UL94-V-0, ASTM2863-77
8	Fungus resistance	Fungus test	Required only if fungus is a concern
9	Susceptibility to Electrostatic Discharge Sensitivity (ESD)	ESD	TM 3015
10	Susceptibility to latchup	Latchup test	JESD 17 or manufacturers internal procedures
11	Thermal resistance	Thermal characteristics	TM 1012

1/ Performed as either characterization or as part of qualification

2/ The manufacturer shall define a "preconditioning" procedure that simulates board assembly of plastic surface mount devices. This procedure should include moisture intake and reflow simulation. Exposure to soldering fluxes (possible source of corrosiveness) and to board cleaning agents is also recommended for preconditioning the devices.

3/ 500 hours of HAST is preferred, but the qualifying activity will consider the manufacturer's overall processing and testing to evaluate this requirement. The actual HAST hours or alternate testing will be included in the Quality Management plan.

2.3.2 JEDEC 26 - General Specification for Plastic Encapsulated Microcircuits for Use in Rugged Applications

JEDEC 26 is an industry prepared specification that establishes uniform requirements for product capability and demonstrated reliability for encapsulated (non-cavity) microcircuits in systems requiring ruggedized performance. It includes certification and quality conformance criteria. The scope states that detail performance requirements, specific characteristics of microcircuits,

product or application limitations, and other provisions which are sensitive to the particular use intended shall be clearly stated by the device manufacturer in a format that is easily understood by the user. The development of this document started in the 80's, was actively worked on in the early 90's and is currently being coordinated by a task group under the chairmanship of Philipp wh Schuessler of Loral Federal Systems in Owego, New York. Two unique qualities have been added to this document which should now make it acceptable to both the DoD customer and the device supplier. Specifically, certification and major change compliance data may now be grandfathered in whole, or by subsection, by mutual agreement between the seller and the buyer. The second statement that helps bridge the issue of Quality Conformance Inspection (QCI) and screening, normally required by the DoD, advances the idea that ISO 9000, or an alternative TQM/SPC program such as those under MIL-PRF-38535, can be used in lieu of the QCI and screening functions. Lastly, a standardized Highly Accelerated Stress Test (HAST) criteria of 130°C/85% RH/500-hr, with bias, has been identified. It is anticipated, however, that these parameters will change as the OEMs continue to provide additional reliability data for this accelerated test.

The last letter ballot results of JEDEC STD 26 were approved for submission to JEDEC Council for final release in January 1995. However, two organizations within council still took exception to the requirement of 500 hours of HAST Testing for rugged parts. Latest results of this effort are included in 2.12.2.5. As of this publication date, however, JEDEC council acceptance has not yet been achieved.

2.4 Microcircuit Application Handbook (MIL-HDBK-179)

This handbook provides guidance on the selection of microcircuit suppliers and parts. The document stresses the importance of knowing your supplier; allows the equipment contractor to be responsible for his vendor and part selection; and expects best commercial practice (BCP) suppliers to supply quality and reliability data. Some features of the handbook are:

- Currently identifies space application as the only use environment which prohibits BCP qualified PEMs
- Requires a Parts Control Plan (PCP) methodology for selection of suppliers and parts
- Establishes a Selection criteria base

Selection criteria is based on:

Supplier - Past experience
Implementation of continuous quality improvement
Employee training
Responsiveness

Part - Availability
Delivery schedule
SPC
In-process testing
Reliability data

The "A" version of this handbook has been coordinated and released as a Tri-Service Handbook. Major changes are as follows:

- Separate selection criteria for supplier and part
- Simplification of environmental use matrix
- Automotive qualification system

Future anticipated changes include:

- Addition of semiconductor devices and passive components
- Implementation of the handbook as a nationalized document

2.5 Fundamentals of Plastic Encapsulated Microcircuits (PEMs) for Space Applications (Draft)

The NASA Goddard Parts Project Office (NPPO) prepared this report to educate NASA personnel and NASA contractors concerning the use of PEMs. Additionally, it is intended for use as a guideline for reviewing industry and DoD PEM assessment, test and evaluation procedures and specifications. The following summarizes the contents of the referenced report:

- Advantages of Using PEMs
- Disadvantages of Using PEMs
- Reliability Studies on PEMs
- PEM Construction
- PEM Defects
- PEM Failure Mechanisms and Modes
- PEM Evaluation Techniques
- Board Assembly Effects on PEMs

- Space Mission Effects
- Screening of PEMs
- Qualification of PEMs
- Handling and Storage of PEMs
- PEM Ideal Attributes
- PEM Acquisition Strategy
- Applicable Government and Industry Standards
- Suggested Readings
- History of PEMs
- Significant Changes to PEMs in the Last Eight Years
- Summary of Reliability Studies Performed on PEMs
- Deflash
- Polymer Die Attach Materials
- Solder Die Attach Materials Gold Eutectic Die
- Attach Materials
- Pareto Ranking Comparison of Failure Mechanisms
- Procedures for DPA of PEMs
- Floor Life of Desiccant Packet Components Upon Opening Of Moisture Barrier Bag
- When Prequalification Testing is Required
- Packing Materials

For further information concerning this report contact:

Nick Virmani NPPO/UNISYS 4700 Boston Way Lanham, MD 20706	or	Gregory Rose NASA (Parts Project Office) Goddard Space Flight Center Greenbelt, MD 20771

2.6 DESC Plastic Vendor Audits

The Defense Electronic Supply Center (DESC), responsible for the audit/validation of vendors/devices used for U.S. DoD applications, has implemented a plastic certification program. U.S. component manufacturers seeking military certification for their plastic packaged products under the DESC Qualified Manufacturing List (QML) standard will undergo DESC audit.

Table 2.6-1 illustrates the DESC FY95 third quarter Progress Report and provides vendor QML status and current plans for becoming QML approved for plastics.

TABLE 2.6-1: DESC FY95 THIRD QUARTER PROGRESS REPORT

Company	QML Status	Status	Projected Date for QML Plastics
AMI	Full QML	Pursuing QML	Unknown at this time
AT&T	Full QML	Pursuing QML	Unknown at this time
Analog Devices	Transition	Evaluating QML	Unknown at this time
Cypress	Transition	Approved	1
Harris	Transition	Evaluating QML	Unknown at this time
Honeywell	Full QML	Pursuing QML	Unknown at this time
Intel	Full QML	Pursuing QML	2
Linear Technology	Transition	Pursuing QML	Unknown at this time
Linfinity	Transition	Evaluating QML	Unknown at this time
Loral	Full QML	Pursuing QML	Unknown at this time
National	Transition	Pursuing QML	Unknown at this time
Philips	Transition	Approved	3
Siliconix	Transition	Pursuing QML	Unknown at this time
Texas Instruments	Full QML	Approved	4
UTMC	Transition	Pursuing QML	Unknown at this time

Notes:

1. Cypress received approval for plastics at its subcontractor Alphatek in Bangkok, Thailand 6 June 95.
2. Assessment package submitted to DESC-ELSC in June 95.
3. Philips received approval for its plastics facility in Bangkok, Thailand 21 December 94.
4. TI is currently approved for QML plastics at its Malaysia, Taiwan, Singapore and Sherman, Texas facilities. All products produced at these facilities are eligible for QML listing, however, TI's marketing group has stated products offered in plastic will be market driven. Contact TI for further information.

Table 2.6-2 is a list of plastic devices that are on the QML.

TABLE 2.6-2: QML PEM LISTING

Generic PN	SMD Number	Package	Source
TLC193MDQ	5962-9555191NXD	8 Pin SOIC	Texas Instruments
TLC2272MDQ	5962-9555201NXD	8 Pin SOIC	Texas Instruments
TLC27L7MDQ	5962-9555301NXD	8 Pin SOIC	Texas Instruments
TLC27L9MDQ	5962-9555401NXD	8 Pin SOIC	Texas Instruments
54ABT32501PZ	5962-9557601NXD	100 Lead Quad Flat Pack	Texas Instruments
54ABT32245PZ	5962-9557701NXD	100 Lead Quad Flat Pack	Texas Instruments
54ABT32543PZ	5962-9557801NXD	100 Lead Quad Flat Pack	Texas Instruments
602	5962-90732/1	Note 2	Philips
604	5962-89564/1	Note 2	Philips
605	5962-90644/1	Note 2	Philips
567	5962-87003/1	Note 2	Philips

1- SMD is in the process of being updated to include plastic. Contact DESC-ELD (Mr. Mike Frye/513-296-5377 or Ms. Monica Poelking/513-296-8525) for more information.

2- Contact Philips (Mr. Jerry Appel/408-991-2165) for available packages.

2.7 Reliability without Hermeticity (RwoH) Programs

The primary objectives of two Reliability without Hermeticity Programs funded by Wright Laboratory at Wright Patterson AFB, OH, were research and development efforts focused on investigating the materials and process technologies needed for producing plastic encapsulated single and multichip packaged microelectronic devices. In parallel with the technology developments were efforts to develop and promote the appropriate test and evaluation methods for assuring high reliability of these technologies in commercial and military environments. While the term "non-hermetic" sometimes carries a negative connotation, a more appropriate term has not been found. It is meant to imply the absence of a conventional inorganic package (metal or ceramic) which has a sealed cavity. In "non-hermetic" applications, reliability is achieved by using coatings technology, and not necessarily by eliminating moisture penetration as in the conventional package. One project sponsored by Wright Laboratory which has been completed was jointly conducted by National Semiconductor Corporation and Dow Corning Corporation. Specific questions which the project addressed are whether the Dow Corning ceramic die coatings:

- Significantly increase the moisture reliability of plastic packaged ICs
- Would survive under extended temperature cycle conditions or in totally saturated atmospheres
- In plastic packages compare favorably to the moisture reliability of ICs assembled in hermetic (ceramic) packages
- Could be applied in a production environment
- Could be economically applied, and have potential commercial viability
- Meet present and future customer needs for improved reliability of packaged or bare die

To assure that results simulated a real life manufacturing environment, all assembly operations were performed by National Semiconductor using standard production materials and production type equipment. Aside from steps required to transport materials and apply the ceramic coatings at Dow Corning, no special precautions were taken in either the fabrication or assembly operations. For the two device types tested (National CD4011B Quad NAND Gate in plastic 14-lead

DIPs; National LM124 Linear Amplifier TAB device in a plastic 40-lead QFP), failure was defined as a non-operational IC attributed to moisture and/or ion induced corrosion on any area of the die. Conditions that were not considered failures for this program were (1) device overstress, (2) package-related defects, (3) interconnect or board-related defects, and (4) device infant mortality.

A summary of the CD4011B test devices concluded that:

- The application of the Dow Corning ceramic coatings did not degrade the reliability of the ICs in extended temperature cycle or autoclave testing
- The ceramic coatings did provide a significant improvement in plastic package moisture reliability under severe HAST conditions
- The data suggests that Dow Corning ceramic coatings can provide a two-times improvement in Mean Time To Failure (MTTF) in plastic package moisture reliability
- The data and process development experience suggests that sealing the die at the wafer level will be an effective alternative for achieving moisture reliability
- Sealing the die at the wafer level will be particularly appropriate for the manufacture of bare die/known-good-die for single or multi-chip applications

Specific conclusions regarding the results of the CD4011B test program are presented in two categories, plastic and hermetic packaged devices, and die in ceramic side-brazed unlidded chip-carrier assemblies. The conclusions for the former category are that:

- The reliability of ceramic-coated die in plastic packages begins to approach that of hermetic packaging when subjected to direct or sequential HAST exposure at 159°C
- The reliability of ceramic-coated die in plastic packages surpasses that of standard die in similar packages when subjected to direct or sequential HAST exposure at 159°C
- The ceramic coating materials and processes do not degrade IC performance in assembly or in extended temperature cycling (+150°C to -65°C) and autoclave (121°C, 100% RH) exposures

- The use of thin-film ceramic coatings protected the ICs from moisture and corrosive ions, which significantly increases the device lifetime (by a factor of 3)

- Device preconditioning (24-hour autoclave, followed by 200 temperature cycles) accelerates the time to failure by 100% in HAST exposure of plastic packaged CMOS devices

- No change in failure mode was revealed between devices subjected directly to HAST or those subjected to sequential HAST exposure

- Standard die in plastic packages (standard PDIPs) failed by classical bond pad corrosion mechanisms

- When compared to standard PDIPs, ceramic coated die in plastic packages failed (prior to 800 hours) by non-classical mechanisms, some of which are not clearly understood

- Standard die in hermetic packages failed by classical mechanisms not related to the RwoH study: anodic dissolution/migration of biased aluminum, aluminum-silicon alloying, and electrical current overstress

The conclusions for CD4011B die in ceramic side-brazed unlidded chip carrier packages (no plastic) are:

- The reliability of ceramic coated die in open cavity packages exceeds that of standard die in similar packages in all reliability testing: autoclave, HAST and temperature cycling/salt fog exposures

- Standard die in unlidded chip carriers failed due to severe lead wire and bond pad corrosion, regardless of reliability test exposure

- Ceramic coated die in unlidded chip carriers failed due to isolated lead wire corrosion at the neckdown-to-frame region. No die or bond pad corrosion failures were revealed in autoclave or temperature cycling/salt fog exposures. Extended exposures in HAST revealed anodic dissolution/migration of biased aluminum, aluminum-silicon alloying, and electrical current overstress (not related to the RwoH study)

- Device preconditioning (24-hour autoclave, followed by 200 temperature cycles) accelerates the time to failure of CMOS devices in unlidded chip carriers in all reliability testing

- Ceramic coated aluminum lead wires not protected from mechanical shock and vibration (device preconditioning) are susceptible to fracture at high stress regions (neckdown to frame). The use of gold wire or additional mechanical protection may be required to reduce lead wire movement

The program conclusions for the LM124 test devices indicate that:

- The Dow Corning ceramic coating does not degrade the electrical performance of the IC in assembly, burn-in, or surface-mount technology (SMT) board assembly.
- The HAST results at 140°C do not differentiate the reliability among coated TapePak™, uncoated TapePak™, and hermetic control devices.
- The HAST results at 140°C do not differentiate the reliability among coated PDIPs, uncoated PDIPs, and hermetic control devices.
- The HAST results at 140°C indicate that TapePak™ and plastic packaging technology is more robust in HAST than PCB and fine-pitch solder technology.
- Analysis of the devices before and after HAST at 140°C by photoemission microscopy does not indicate any detectable flaws in either the standard device passivation scheme or the Dow Corning ceramic coating.
- At present, hermetic packages still provide the most robust moisture protection.

2.8 DLA/DoD Plastic Package Availability Program

In line with the effort to transition the sale of plastic packaged devices to the military, the DoD initiated an effort to provide suitable guidelines for plastic packages targeted for military applications. The DoD Plastic Package Availability Program is managed by the Defense Logistics Agency (DLA), but in reality is a tri-service initiative. The affiliations of the review board members are presented in Table 2.8-1.

TABLE 2.8-1: AFFILIATIONS OF DOD PLASTIC PACKAGE AVAILABILITY PROGRAM REVIEW BOARD MEMBERS

Service	Location	Review Board Member
DLA	Dayton, OH	Bob Tonar (Program Manager)
Air Force	Rome Laboratory/ERDR Rome, NY	James Reilly
Army	MICOM, Redstone Arsenal, AL	Noel Donlin
Navy	Naval Surface Warfare Center Crane, IN	Dan Quearry
DESC	Dayton, OH	Greg Pitz/Monica Poelking
NASA	Goddard Space Flight Center Greenbelt, MD	Bob Savage
DoD	Washington, DC	Leon Lantz

The charter of this program is to develop the specific details required to generate a suitable specification for plastic-encapsulated devices in military applications. Industrial suppliers are included in Table 2.8-2.

TABLE 2.8-2: INDUSTRIAL SUPPLIERS

Company	Expertise
National Semiconductor Corp.	Major Device Supplier
Plaskon Electronic Materials	Expertise in compounding of semiconductor-grade epoxy molding materials
Honeywell, Inc.	Supplier of avionic/military systems utilizing both hermetic and plastic packaged devices
Dow Corning Corp.	Expertise in thin-film materials for hermetic barrier coatings
Sandia National Laboratories	Experience with sensors designed for evaluating assembly-related reliability

The results of this study will establish an extensive compendium of information on plastic package design, materials, manufacturing procedures, test procedures, and device reliability within the DoD, which can subsequently serve as the basis for developing plastic package device specifications.

The primary objective of the study is to provide the data necessary for the DoD to revise its specification concerning the use of PEMs in military systems. To this end, the study hopes to identify technology design and process improvements that can migrate to and upgrade the mainstream plastic package manufacturing technology by correlating them to the application of plastic packages in military applications.

The role of each team member is defined in Table 2.8-3.

TABLE 2.8-3: ROLE OF TEAM MEMBERS ON DLA MANTECH PROGRAM

Team Member	Description Of Role
Honeywell, Inc.	1. Survey of Honeywell avionic systems that incorporate both plastic & hermetic devices to assess: • Screening/qualification requirements for plastic parts • Vendor selection process • Specification and procurement practices for plastic and ceramic ICs • Part processing, production and repair flow **DELIVERABLE: Report on system considerations for the replacement of hermetic ICs with plastic ICs.** 2. Provide actual system field performance data for plastic (versus hermetic) devices to: • Determine a relational path from test environment to failure type • Establish short term and long term reliability compliance • Contrast reliability prediction methodologies for ceramic vs. plastic devices • Perform failure analysis on fielded systems **DELIVERABLE: Detailed report comparing the field performance of hermetic and plastic-encapsulated devices.**
Plaskon Electronic Materials	1. Review the current state-of-the-art in plastic package technology to: • Establish both internal data and a customer base • Select a general purpose and low stress Epoxy Molding Compound (EMC) • Formulate high/low stress and popcorn resistant materials and characterize them **DELIVERABLE: Develop a preliminary specification for Epoxy Molding Compound (EMC).**
Sandia National Laboratories	1. Detect moisture arriving at the surface of a chip through: • Design of a chip that will sense moisture on the surface of a die and monitor corrosion of the metallization • Development of a test chamber and procedure, to be calibrated and documented • Assessment of RwoH coatings during HAST performance **DELIVERABLE: Develop a test specification, similar to MIL-STD-883, Method 1014.**
Dow Corning Corp.	1. Determine the effectiveness of inorganic barrier (i.e. RwoH) coatings for improving the hermeticity of plastic-encapsulated ICs by: • Designing appropriate masks • Optimizing the deposition process • Applying RwoH coating to assembled devices **DELIVERABLE: Documented procedure for the application of silica/ silicon carbide thin films for plastic-encapsulated ICs.**

TABLE 2.8-3: ROLE OF TEAM MEMBERS ON DLA MANTECH PROGRAM (CONT'D)

Team Member	Description Of Role
National Semiconductor Corp.	1. Assemble high and low lead count devices to enable comparison of Plaskon molding compounds: • With/Without RwoH coating (low lead count) • Where relevant, include the Sandia moisture sensor • Controlled conditions throughout **DELIVERABLE: Eleven groups of plastic-encapsulated devices, assembled with the appropriate controls and wafer traceability.** 2. Compare the performance of two commercial-grade Epoxy Molding Compounds (EMCs), optimized versions of these EMCs, anti-popcorn EMCs, and Dow Corning RwoH coatings: • Review all input on test plan with the customer • Propose reliability testing similar to MIL-STD-883, Groups A, B, C, D • Benchmark test results to the current database • Develop a model for the Sandia test chip **DELIVERABLE: Report on reliability performance.** 3. Summarize recommendations based on input from all previous tasks: • Survey of construction materials and industry poll • System level requirements • Result of RwoH coatings and Sandia sensor • Required controls for assembly of devices and systems • Review of alternate test conditions **DELIVERABLE: Report which summarizes performance-based guidelines, to assist the government in defining operating environments for plastic-encapsulated ICs.**

The devices which will be tested and evaluated in the program are listed in Table 2.8-4.

TABLE 2.8-4: DEMONSTRATION TEST VEHICLES

• Low lead-count device (14L) - LM124 quad amp in MDIP & SOIC pkgs. - CERDIP control parts
• High lead-count device (68L) - SCX6244PLCC ASIC CMOS gate array - 259 X 262 MIL 2 - CERQUAD control parts
• Sandia Triple Track "NAT-01" moisture corrosion sensor

The various products, materials and test conditions that make up the design of experiments are noted in Table 2.8-5.

TABLE 2.8-5: DESIGN OF EXPERIMENTS (DOE) SUMMARY

• Eight mold compounds
• Two product chips & one sensor chip
• Three plastic packages & two ceramics
• Precondition vs. no precondition
• Two operating voltages

Initial results from the program are available. Indications are that significant increases in accelerated test reliability can be achieved through the use of improved molding compounds.

The latest program results were presented at the:

Fourth Annual SHARP Commercial & Plastic Components In Military Applications Workshop

15 & 16 November 1995
Westin Hotel, Indianapolis, Indiana

For further information contact:

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Crane, IN 47522-5060

2.9 Army Evaluation/Use of Plastic Encapsulated Microcircuits

A few high-profile, front-line U.S. Army programs have given, or are in the process of giving, preliminary approval for contractors to use PEMs in developmental electronic systems, with expectations that they will be approved for use in full production units in the future. Most notable among these announcements are those outlined in Table 2.9-1.

TABLE 2.9-1: U.S. ARMY ANNOUNCEMENTS REGARDING USE OF PEMS

• Commanche Scout/Attack Helicopter Program	• Use PEMS where appropriate • Most historical PEM problems have been overcome • Candidates for PEM insertion: - avionics - mission equipment package - electrical systems - weapons systems
• Single Channel Ground and Airborne Radio System (SINCGARS)	• Contractor proposals submitted to the Army Best Commercial Practice (BCP) for a pilot program to evaluate PEM suitability • Results of pilot program, including assessment of reliability, mission and application requirements, will determine PEM usage in the SINCGARS production program
• Battlefield Combat Identification System (BCIS)	• Approved use of PEMs • Army CECOM has determined PEMs should be used wherever possible
• Army NDI Programs: - Mobile Subscriber Equipment (MSE) - Precision Lightweight GPS Receiver (PLGR)	• Reliability field study funding approved for some NDI systems • Reliability audits will include hundreds of PEMs • Systems range from controlled environments to field use
Potential military systems w/plastics	• MX 762 - Fuze • TACCS - Tactical Army Combat Computer Service • AN/TRS-2 - PEWS - Platoon Early Warning System

The Army Research Laboratory awarded an 18 month contract entitled "A Reliability Audit of PEMs Used In Fielded NDI Systems" which started on 30 September 1994. The contractor is Rockwell International, Collins Avionics and Communications Division, Cedar Rapids, Iowa. The system to be monitored is the AN/PSN-11 PLGR (Precision Lightweight GPS Receiver). The system characteristics are as follows:

- Hand held<2.75 pounds
- <90 cubic inches
- MTBF: 23000 hours
- Operating temperature: -20 to 70°C
- Storage temperature: -57 to 70°C
- Relative humidity: 0 to 100%
- 32 Surface Mount Technology (SMT) microcircuits
- Plastic SMT packages up to 160, 180 & 208 pins
- 53 plastic encapsulated transistors and diodes
- >20K PLGRs built to date
- 30K per year for next two years
- Six year warranty
- Initial cost: $1,300/unit
- After five years: $800.00/unit

The program will assess system and PEM reliability and provide:

- Procurement data (vendor ID, supplier and part selection rationale, hermetic vs. PEM cost comparison, test requirements, temperature performance requirements, etc.).
- Reject rate data at various test points in equipment manufacturing
- Field reliability estimates for use environments of system and PEMs
- PEM fault isolation and removal from field returned boards
- Failure diagnostics of production rejects and field returned removals
- Based on their experience and these data, propose a Technology Insertion Plan for PEMs

Table 2.9-2 lists the number of PLGR fielded units.

TABLE 2.9-2: SUMMARY OF PLGR FIELDED UNITS
CUMULATIVE TOTAL FIELDED

Customer	Aug 94	Sept 94	Oct 94	Nov 94	Dec 94
Army	8,798	9,138	11,846	12,235	12,489
Air Force	2,641	2,893	3,630	3,836	4,033
Marine Corp	668	2,284	2,284	2,284	2,284
Navy	2,218	2,218	2,595	2,595	2,595
USDA	-	-	168	168	168
Canada	-	-	240	240	240
Totals	14,325	16,533	20,763	21,358	21,809

2.10 Swedish - Bofors

The Swedish company, Bofors, has been involved in a study of plastic encapsulated microelectronic devices (PEDs) for potential use in military equipment. The funding for the program has come from the Swedish Defense Material Administration (FMV) through its missile material command and is in its third phase:

- Phase 1: 1990-1991 Feasibility Study - Market survey and technology status
- Phase 2: 1991-1993 Qualification and Reliability - Methodology
- Phase 3: 1993-1995 Production Aspects (System Level) - Pilot qualifications

Second-phase studies, buoyed by a great increase in PED reliability based on previous experience, centered around methods and procedures for device quality and reliability assurance. A qualification methodology has been developed, based

primarily on "de facto" industry standard tests such as Highly Accelerated Stress Testing (HAST) with preconditioning, as illustrated in Figure 2.10-1. This qualification effort is intended to be more manufacturer oriented than type oriented, which is in line with the QML approach currently being developed in the U.S. The main direction for the Swedish defense industry is to qualify components through the manufacturer's own quality conformance inspection (QCI) and qualification data, as well as through extensive audits at the wafer fab and assembly sites.

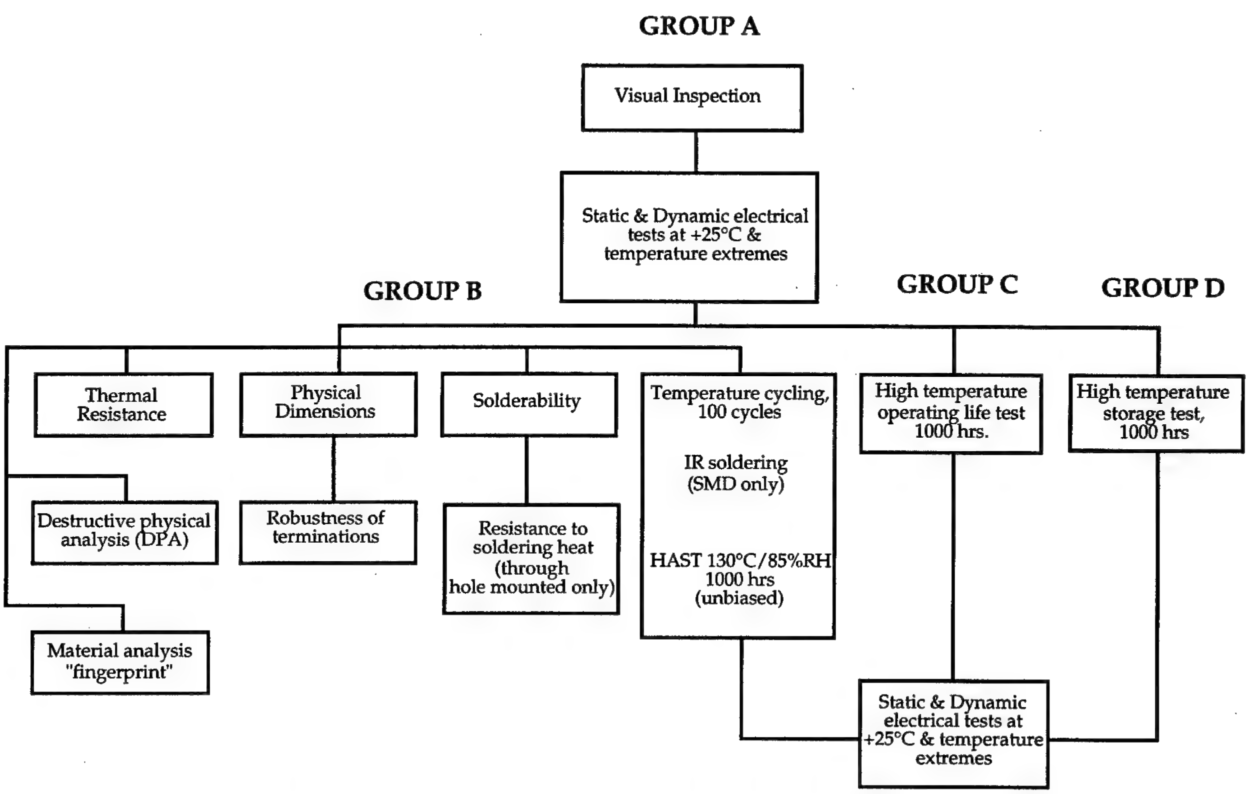

FIGURE 2.10-1: QUALIFICATION METHODOLOGY

Bofors was awarded a contract from FMV to proceed with the third phase of the study in August, 1993. This phase will deal primarily with production problems associated with PEDs, mainly with regards to Surface Mount Technology (SMT), as well as validation of the PED qualification approach developed during Phase 2. The validation will be performed via pilot projects with a number of vendors using their internal QCI approaches. This task is being coordinated through the FMV:Telelab and "AG8", a working group consisting of representatives from the components departments throughout the Swedish defense industry.

A potential fourth phase of the project would involve a practical study of the reliability of state-of-the-art components such as VHSIC, as well as the compilation of a "PED Application Handbook", which would provide guidelines on PED environmental limitations, type/vendor selection criteria, test methods, QCI, and production requirements.

2.11 NASA - Lockheed Sealed Chip-on-Board (SCOB)

The National Aeronautics and Space Administration (NASA) has accepted the use of Sealed Chip-on-Board (SCOB) devices developed by the Space Sciences Laboratory of the Lockheed Research and Development Division on the Global Geospace Science (GGS) program POLAR satellite. The SCOB approach involves direct attach of integrated circuit die to a fine line printed wiring board (PWB), which is analogous to the conventional printed circuit board (PCB), but which allows ultra fine pitch conductors leading to very high density component placement. No additional separate package is used to encase the assembled die, thereby dramatically reducing size and weight. Organic silicone gel encapsulates applied over the finished SCOB assemblies to provide mechanical protection have provided limited success in establishing an environmental barrier. Extensive work has been done in the application of Ionic Systems RelSeal™ silicon nitride using their ColdCoat™ room temperature plasma chemical vapor deposition system, and various encapsulates for use over the nitride to provide high levels of reliability with SCOB. Based on test results, the proposed SCOB process has been recommended for use in the GGS program. The results of the SCOB evaluation have been provided to the RELTECH program, a joint government and industry program for reliability technology to achieve insertion of advanced packaging. The first SCOB assemblies protected with room temperature silicon nitride will be used on the detector assemblies of the Comprehensive Energetic Particle Pitch Angle Distribution/Source/Loss-Cone Energy Particle Spectrometer (CEPPAD/SEPS) instrument, which will be part of the 1994 POLAR satellite launch.

2.12 Rome Laboratory (RL) Acquisition Reform Programs Support

Even before the Dr. William Perry memorandum, of 29 June 1994, stating the DoD policy to streamline DoD purchasing practices and procedures, Rome Laboratory had been actively involved in programs addressing the needs cited in

the memorandum. Stressed in this memo was leveraging the use of best commercial practices and parts to drive down the cost of DoD systems, while maintaining comparable levels of quality and reliability. Two specific programs are discussed in this section, with numerous other support and in-house efforts being performed at Rome Laboratory.

The first program is the "The Best Commercial/Industry Components and Practices (BCIC) Initiative", an effort sponsored by ESC/JTIDS, which is evaluating and comparing the reliability of circuit boards assembled using commercial components and processes to those assembled using full military specification compliant components and processes. A receiver/synthesizer board originally designed and assembled under the Joint Tactical Information Distribution (JTIDS) Product Improvement Plan, and which applies a variety of technologies including RF, digital, through hole, and surface mount components and processes, was selected as the test case. Six board configurations will be built using a combination of three components and two process types. The assembly processes being compared are a full military compliant line and commercial process line which produces high quality commercial avionics. The three component types used to populate the boards include MIL-STD-883 screened, military specification components; components with reduced screening; and commercial plastic encapsulated microcircuits.

The purpose of this initiative is twofold:

a. Investigate the differences in quality and reliability between Printed Wiring Assemblies (PWAs) built using commercial components and processes for use in harsh environments, and those built using full military parts and processes. This initiative is predicated on the intent to demonstrate a statistically significant difference in both parameters.

b. Develop guidelines and recommendations concerning commercial military integration.

This program is completing its third phase with testing completed and data analysis initiated.

The second program is titled "Military Products from Commercial Lines Pilot Program," an effort sponsored by Wright Laboratory, Manufacturing

Technology Directorate. The objective of this pilot is to demonstrate the production of military components on a commercial automotive line at lower cost and comparable quality to those produced on a dedicated military line. Electronic boards for the F-22 Advanced Tactical Fighter and the RAH-66 Commanche Helicopter have been targeted. Data collected throughout the program will be used to determine if the F-22 and RAH-66 can achieve appropriate cost savings, quality and reliability to warrant future purchases of commercially manufactured military electronic modules from an automotive line. The pilot is using an integrated product team (IPT) approach, and is addressing business policies and practices (BP&P), manufacturing infrastructure (MI), and process technology (PT). The BP&P team is focusing on breaking down current policy barriers and changing regulatory procedures for specific reporting requirements that would discourage a potential offerer from bidding on government acquisition programs. Rome Laboratory is participating on this team. The MI efforts are implementing a concurrent engineering environment to enable team communication and a producible design, and are enhancing computer integrated manufacturing to optimize throughput and capital utilization. Efforts in the PT area involve characterization of existing commercial capabilities, re-designing of military modules for commercial production, and processing of prototype modules for validating BP&P and MI changes. These modules are being fabricated with plastic encapsulated microcircuits and automotive processes and will undergo environmental stress testing to assure reliable operation in the F-22 and RAH-66. This program is in its initial phase. Module prototype builds and environmental testing will be performed throughout the duration of the program, which is scheduled for completion in 1997-1998.

These initiatives, combined with the Rome Laboratory in-house assessments on the reliability of plastic encapsulated microcircuits for use in military systems, will provide system program offices with the necessary information to perform a risk assessment when trying to employ commercial practices and components on their systems. An Acquisition Guidance Document entitled "Commercial Parts and Processes for Military Applications" is planned and will document the results of these and other efforts. This document can then be utilized by the system program offices to help them implement DoD Acquisition Reform Policies.

2.12.1 RL/MICOM PEM Long Term Storage Reliability Program

Rome Laboratory and the U.S. Army MICOM have initiated a five year Plastic Encapsulated Microcircuit Long Term Storage Program. The program was initiated due to MICOM's concern that there is a lack of data supporting the decision to use plastic encapsulated microcircuits (PEMs) in systems requiring long term storage (20-year non-operating life requirement for missiles). The reliability program includes 300 parts each (CD4011 CMOS in a 14 pin DIP configuration) from five suppliers which will be stored in four environments/locations: Arctic (Griffiss AFB, NY), Desert (Yuma Army Depot, AZ), Tropical (Eglin AFB, FL), and "Normal" (Redstone Arsenal, AL). This CMOS part is the same one that was used in the DLA Plastic Packaging Availability Program, and the earlier "Reliability Without Hermeticity (RwoH)" Program. Data available from the accelerated testing conducted on these other programs will assist correlation analysis of the obtained PEM dormant storage data.

Electrical baseline testing and data logging of all 1500 parts was conducted by Rome Laboratory at five temperatures (-55°C, -40°C, 25°C, 85°C, and 125°C). A sampling of five parts from each manufacturer was subjected to acoustic analysis. MICOM assembled 220 functional parts per supplier to the printed wiring boards (PWBs). The parts and PWBs on which they were assembled were not conformal coated. Each PWB, representative of board types used by MICOM missile contractors, incorporates one PEM. The parts were then retested by RL/ERDD at room temperature (25°C). Fifty assemblies (PWB + PEM) per supplier were placed into four storage containers in Fall 1994. The storage container is the same as would be normally used for long term, non-operating missile system storage. Temperature and humidity data loggers have been included with the assemblies inside the storage containers. The assemblies which were placed in storage will be tested once a year until that supplier reaches 50% failures at each specific location, or until the assemblies complete 5 years under test, and the data will be collected annually by MICOM. Rome Laboratory will conduct any required electrical tests and part failure analysis.

Wide variations existing in "best commercial practice" manufacturing quality in devices analyzed as part of this program have been demonstrated. A C-

Mode Scanning Acoustic Microscope (C-SAM) was used to identify delamination or other packaging abnormalities. Ten parts total, from two 1994 date code lots of devices from Manufacturer B, were examined. All devices examined from each manufacturer show a consistent difference in the level of manufacturing quality. When virgin parts of a mature PEM technology (14 lead dual in-line packages), produced by two well known and widely respected "best commercial practice" manufacturers, show such wide variations in manufacturing quality, it is a mistake to simply advise SPOs to "buy commercial".

2.12.2 Rome Laboratory Helping to Make DoD Procurement Offices "Smart Buyers"

Changes in the microelectronics industry and directives from the Office of the Secretary of Defense are rapidly impacting the way in which the System Program Offices (SPO) must work. One of these changes is a push for the SPOs to use, in military applications, plastic encapsulated microcircuits (PEMs) designed and manufactured for commercial applications. There are certainly places for PEMs in military applications, but the questions we must answer are "Which applications and which PEMs?"

Virtually all published data indicates the quality and reliability of PEMs have improved dramatically over the years. However, the data also indicates that the quality and reliability of PEMs varies widely. These variations seem to be related to factors such as manufacturer, device type, package style, and application environment. RL is developing the knowledge and tools that System Program Offices need to make decisions for their systems and for the DoD. The rallying cry "use best commercial practice" is only meaningful if the SPOs know how to buy products which are suitable for their system and cost effective for the DoD in the long run.

2.12.2.1 Destructive Physical Analysis Results

An example of previous work by RL is the destructive physical analyses (DPAs) performed on commercial parts to be used in a DoD system. The results indicated that manufacturing quality problems existed with each PEM device evaluated, despite manufacturers' claims that the parts would pass the DPA

criteria. The SPO used this information in conjunction with knowledge of the application environment to evaluate the cost, schedule, and performance risks to the system.

2.12.2.2 Smart Targeted Fire And Forget Programs

Another example of past work involved the Army's STAFF (Smart Targeted Fire and Forget) program fuses for M1A1 tank ammunition. The manufacturer approached RL after noticing an apparent "popcorn" problem with one device type. The manufacturer's test and evaluation, combined with C-SAM analysis at RL, confirmed a high susceptibility of the parts to "popcorn" damage during soldering. Due to the poor board level assembly yield, the potential for long term reliability risk stemming from damage induced during soldering, and the possibility that a "popcorn" type failure could occur upon firing of the missile, the manufacturer decided that the PEM was not suitable for this application. It was replaced with a hermetic part.

2.12.2.3 JEDEC 26-A

RL previously worked with LORAL Federal Systems Division (Mr. Philipp Schuessler) and the JEDEC 26-A committee on JEDEC Standard 26-A "General Specification for Plastic Encapsulated Microcircuits For Use In Commercial And Rugged Applications". Unfortunately, the final acceptance of the standard has been delayed by the objections of two manufacturers. The document requires that either the device manufacturer's parts meet stringent qualification tests, or that the manufacturer commit to provide customer service to the users of the devices. The intent is to make sure that the parts are either the best available, or that the manufacturer and users discuss the suitability of the device for the specific application. This type of communication is an essential part of "best commercial practice" and is usually not provided to customers buying small quantities of commercial parts from distribution. It appears the manufacturers want to be able to label the parts as "rugged" without demonstrating it in any standard way, and to claim "best commercial practice" without committing resources to support the customer. This effort highlights the need for the DoD to review available and proposed industry standards and assure that they are compatible for DoD use. RL is continuing to push for the final acceptance of this document. However, other

avenues will be pursued, if necessary, to provide a workable PEM specification for the SPO and industry use.

2.12.2.4 French Ministry Of Defense DEA

A Data Exchange Agreement (DEA) between RL and the French Ministry of Defense (MOD) is another effort being undertaken. The DEA will trade RL TSMD (Time Stress Measurement Device) information and reliability prediction techniques for MOD data on PEM selection and accelerated test data. Rome Labs will focus its in-house efforts on the PEMs and applications in which industry is experiencing the highest field failure rates. For example, one commercial manufacturer has observed that failure rates for PEMs vary by more than three orders of magnitude for different device types within the same application environment. Reductions in the highest failure rates will make significant improvements in the overall system reliability. These dual-use joint efforts will lead to better evaluation procedures and improvements in the devices.

2.12.2.5 Summary

The efforts discussed in Section 2.12.2 have demonstrated that there are risks involved with the use of PEMs in military applications. Discrepancies exist between the claims of some commercial manufacturers and actual device attributes. Some PEMs designed and manufactured for commercial use are not suitable for military applications. The operating temperatures and physical design margins make some PEMs inappropriate for critical military/space systems. However, these risks can be largely addressed through careful evaluation of the application environment and knowledgeable selection of the PEMs from quality manufacturers. The quality and reliability of commercial PEMs vary widely, but the best appear suitable for use in many DoD applications. Additionally, the DLA PPA program has demonstrated that even for the best commercial manufacturers, significant improvements in reliability can be achieved through the use of improved molding compounds and new die coatings. Efforts to team with successful commercial users of PEMs will accelerate the rate at which useful information is available to the SPOs. Significant accomplishments, furthering the judicious use of PEMs, have been achieved to

date. However, the efforts to reduce the risk of PEM usage need to continue and be expanded.

The advances in the microelectronics industry and directives from the DoD are rapidly changing the environment in which the SPOs must work. RL's goal is to provide the SPOs with the knowledge, guidance and tools needed to answer two critical questions: "In which applications can PEMs be used" and "Which PEMs are appropriate?" The proper answer will assure that project offices are smart buyers of products based on best commercial practices.

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3.0 COMMERCIAL

In the commercial environment, both users and vendors have had a significant impact on the application, manufacture and test of PEMs. The following sections summarize noted commercial activity concerning PEM's.

3.1 Case Studies Symposium in the Successful Use of Commercial Integrated Circuits (ICs) in Military Systems

This symposium was sponsored by the Industry Task Force for Affordability to allow presentation and discussion of the use of commercial ICs in military applications addressing the following topics:

- Experiments and Analysis
- Actual Applications
- Possible Missed Opportunities
- Emerging Activities

The symposium proceedings were published in two volumes. Volume 1 summarizes the symposium and provides background information. Also included is the plan for accelerating the use of commercial ICs in military applications. Volume II presents 20 papers relevant to the topic as illustrated in Appendix B-6, which lists the agenda, the presenters and their affiliation.

3.2 Harris Report on PEM Reliability Considerations

In January 1994, Harris Semiconductor published a report which provided an overview of their experience and recommendations regarding the reliability and use of PEMs in military applications. Harris' approach to PEM reliability is defined through the deployment of proactive programs such as Total Quality Management (TQM), Applying Concurrent Teams to the Product-to-Market cycle (APC-PTM), Statistical Process Control (SPC), and Design for Reliability. Reliability verification is initially achieved through a rigorous qualification testing program at the wafer and the package levels. Continuous product reliability improvement is achieved through a Matrix Monitoring program.

Wafers are fabricated using SPC on-line as an operator tool for controlling and reducing variability in the performed process steps. Critical process steps,

i.e., those that affect quality and reliability, are defined as critical process control nodes. The assembly and test areas are governed by the same Quality System, each maintaining critical node SPC lists to assure maintenance/improvement of quality and reliability over time.

The sampling, qualification and burn-in requirements (when specified) for PEMs, as manufactured by Harris Semiconductor, are generally more stringent than those for military hermetic devices. Table 3.2-1 provides a comparison between military hermetic versus typical automotive PEMs. The quality standard for Average Outgoing Quality (AOQ) level is typically < 50 ppm defective, significantly higher than for Group A of MIL-STD-883.

TABLE 3.2-1. COMPARISON OF GENERAL INDUSTRY SAMPLING AND QUALIFICATIONS FOR MILITARY HERMETIC VS. AUTOMOTIVE PLASTIC MICROCIRCUITS

Description of Test	Military Hermetic (MIL-STD-883)			Automotive Plastic (Typical)		
	LTPD	# LOTS	DURATION	LTPD	# LOTS	DURATION
Burn-In 100%	(PDA = 5%)	All	168 Hours	(PDA = 0.5-2.0%*)	All	48-168 Hours
Operating Life Qualification	5	1	1000 Hours	2-3	1 or 3	1000-2000 Hours
Biased Humidity Qualification	Not Specified	Not Specified	Not Specified	2-3	1 or 3	1000-2000 Hours
Temp Cycle Qualification	15	1	100 Cycles	1.5-3	1 or 3	1000 Cycles
Mechanical Qualification	15	1	---	Not Specified	Not Specified	Not Specified
Group A Sampling	2	All	---	1	All	---

* Values are for when PDA is specified. Sample burn-in to LTPD of 2% typically performed when PDA not specified.

NOTE: This chart compares similar stress conditions with the exception of bias humidity and mechanical.

Current expectations by OEMs are that suppliers of PEMs will use demonstrated effective problem solving disciplines that lead to root-cause identification, and containment and corrective actions. Harris Semiconductor uses cross-functional/site teams to implement Continuous Process Improvement and Design for Reliability techniques, which have resulted in "plastic-packaged semiconductor reliability approaching that of hermetic semiconductors in the temperature range specified for plastic operation". These Best Industry Practices are listed in Table 3.2-2.

TABLE 3.2-2. BEST INDUSTRY PRACTICES - DESIGN FOR RELIABILITY AND CONTINUOUS IMPROVEMENT

DIE RELATED	IMPACT ON RELIABILITY
• Electric (E) Field Plating	- Reduces mobile ion instability
• Particulate & Contaminant Control	- Lowers defects in oxides and ionic contamination
• Layout considerations for high stress areas	- Reduces stress cracking of passivation at die corners
• Denser passivation, sandwich layers of SiO_2/SiN_x	- Better integrity against fabrication defects - Robust to thermomechanical stress - Better moisture/ion barrier
• Passivation overlap of die oxide edges	- Provides moisture/ion barrier
• Advanced planarization for reduced stress	- Reduced metal displacement and passivation damage
• Wear-out mechanisms eliminated from useful life at the die level	- Elimination of electromigration, time dependent dielectric breakdown, hot carrier injection, and corrosion intrinsic wear-out failure mechanisms from die useful life
PACKAGE RELATED	**IMPACT ON RELIABILITY**
• Mold Compounds:	
- Higher glass transition temperatures	- Less thermomechanical stress at high temperatures - More robust to thermal cycling - Reduced corrosion and increased device stability
- Low ionic (low halides, and alkali) compounds	- Reduced point stress damage on die surface
- Use of modified filler material	- Reduced passivation cracking and metal deformation
- Low stress mold compounds for large die and complex geometries	- Corrosion reduction and greater device stability - High temperature stability and corrosion reduction
- Ion getters	- Less wire sweep
- Reduced flame retardants	- Less voids in plastic
- Automated in-line mold machines	- Better control of molding process
• Die attach materials with low stress, low ionics	- Less stress on die - Increased device stability
• Lead lock holes, moisture grooves, locking bars on lead frame	- Increased moisture resistance and corrosion reduction - Increased mechanical integrity
• Optimum die to paddle spacing	- Lower stress on die
• Automated assembly processes	- No human handling, less contamination, and less process variability
• SPC Critical Node List and process monitors	- Variability reduction and continuous improvement
EXPANDED MATERIALS CHARACTERIZATION	**IMPACT ON RELIABILITY**
• Acoustic Microscopy - CSAM - SLAM	- Nondestructive analysis of plastic products for voids, die cracks, and delamination isolation. DOX with CSAM yields continuous improvement.
• Thermal Characterization Methods: - Differential scanning calorimetry - Thermogravimetric analysis - Thermomechanical analysis	- Broader materials characterization and referencing enhances continuous improvement of raw materials
• Moisture weight gain/loss measurements	- Determine sensitivity to delamination and popcorn cracking - Material analysis - Determine dry pack requirements
• Applications of dye penetrants	- Being further developed to enhance tracing moisture ingress on lead frame-to-plastic interfaces

3.3 Stress Test Qualification for Automotive Grade Integrated Circuits

The Chrysler, Delco Electronics, Ford Automotive Electronics Council (CDF-AEC) has prepared and released specification CDF-AEC-Q100 Rev-A "Stress Test Qualification for Automotive-Grade Integrated Circuits," dated 19 May 1995. The CDF-AEC is a cooperative venture between the component engineering groups at the representative corporations. The document defines the minimum stress test-driven qualification requirements and test conditions for the qualification of Integrated Circuits (ICs) for the automotive environment. An "Automotive Grade" part also requires successful completion of a supplier assessment per CDF-AEC-100 "Auditor Guidelines for Quality System Assessment (QSA) for Semiconductor Suppliers". The three automotive grades are defined as follows:

Grade 1: -40°C to +125°C ambient
Grade 2: -40°C to +105°C ambient
Grade 3: -40°C to 85°C ambient

The following documents are referenced within the specification:

Military	
MIL-STD-883	Test Methods and Procedures for Microelectronics
Industrial	
JEDEC JESD-22	Reliability Test Methods for Packaged Devices
UL-STD-94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances
Automotive	
CDF-AEC-A100(draft)	Quality System Assessment(QSA) for Semiconductor Suppliers
CDF-AEC-Q100-001	Bond Shear Test
CDF-AEC-Q100-002	Electrostatic Discharge ESD Sensitivity (HBM) Test
CDF-AEC-Q100-003	Electrostatic Discharge ESD Sensitivity (MM) Test
CDF-AEC-Q100-004	IC Latch-up Test
CDF-AEC-Q100-005	E^2 PROM Endurance Test
CDF-AEC-Q100-006	E^2 PROM Data Retention Test
CDF-AEC-Q100-007	Electro-Thermally Induced Gate Leakage Test

The automotive procedure is similar to the QML approach in that a baseline is established, generic data can be used to satisfy qualification requirements and the supplier has the opportunity to present rationale justifying deletion of required

testing. Another similarity is the performance of testing to assure that wearout failure mechanisms are identified. Generic data is not allowed for:

- Electrostatic Discharge
- Latch-up
- Electrical Distribution

Performance of some environmental stress testing (HTOL, THB, TC, etc.) will be determined by the user's experience with the vendor. Tables 3.3-1 and 3.3-2 identify CDF-AEC-Q100 Rev-A qualification testing and test methods.

TABLE 3.3-1: QUALIFICATION TEST DEFINITIONS

Stress	Abbr.	#	Note	Sample Size per Lot	Number of lots	Accept on # failed
Pre- and Post-Stress Electrical Test	TST	1	H,P,N,G	All qualification parts submitted for testing		0
High Temperature Operating Life	HTOL	2	H,P,D,G	77	3-see note **	0
High Temperature Bake	HTB	3	H,P,D,G	77	1-see note **	0
Preconditioning	PC	4	P,S,N,G	All surface-mount qualification parts to be subjected to THB, TC, AC, PTC		0
Temperature Humidity Bias	THB	5	P,D,G	77	3-see note **	0
Autoclave	AC	6	P,D,G	77	3-see note **	0
Temperature Cycling	TC	7	H,P,D,G	77	3-see note **	0
Power Temperature Cycling	PTC	8	H,P,D,G	77	1	0
Mechanical Shock	MS	9	H,D,G	39	3-see note **	0
Vibration Variable Frequency	WF	10	H,D,G	Performed as a sequential test for mechanical integrity of hermetic packaged devices		
Constant Acceleration	CA	11				
Gross/Fine Leak	GFL	12				
External Visual	EV	13	H,P,N,G	All qualification parts submitted for testing		
Physical Dimensions	PD	14	H,P,D,G	30	1	$P_{pk} \geq 1.66$ or $C_{pk} \geq 1.33$
Lead Integrity	LI	15	H,P,D,G	45 leads from a min. of 5 devices	1	0
Lid Torque	LT	16	H,D,G	5	1	0
Bond Pull Strength	BPS	17	H,P,D,G	30 bonds from a min. of 5 devices	1	0 and $P_{pk} \geq 1.66$ or $C_{pk} \geq 1.33$
Bond Shear (See Appendix 3)	BS	18	H,P,D,G	30 bonds from a min. of 5 devices	1	0 and $P_{pk} \geq 1.66$ or $C_{pk} \geq 1.33$
Die Shear Strength	DSS	19	H,P,D,G	5	1	0
Electrostatic Discharge	ESD	20	H,P,D,G	min. 3V level/model	1	0
Latch-up	LU	21	H,P,D,G	6	1	0
Internal Water Vapor	IWV	22	H,D,G	3	1	0
Solderability	SD	23	H,P,D,G	15	3-see note **	0
E^2PROM Data Endurance/Retention Test	ET	24	H,P,D,G	77	1	0
Early Life Failure Rate	ELFR	25	H,P,N,G	800	3-see note **	0
Electro-Thermally Induced Gate Leakage Test	GL	26	D,P,G	6	1	0
Electrical Distributions	ED	27	H,P,D,G	30	3-see note **	pre: $P_{pk} \geq 1.66$

TABLE 3.3-2: TABLE OF METHODS REFERENCED

Stress	Abrv	#	Reference	Additional Requirements
Pre- and Post- Stress Electrical Test	TST	1	User or supplier specification	Test is performed as specified in the applicable stress reference and the additional requirements in Table 2.
High Temperature Operating Life	HTOL	2	JA108	150°C T_a for 408 hours or 125°C T_a for 1008 hours (junction temperature not to exceed 175°C) at V_{cc} (max) and static or dynamic bias (per engineering spec). Equivalent time-temperature combinations are acceptable. Tri-temp TST and ED before and after HTOL.
High Temperature Bake	HTB	3	JA103	150°C/1000 hours or 175°C/500 hours for plastic and 250°C/10 hours or 200°C/72 hours for ceramic packaged parts. TST before and after at room and hot temperatures.
Preconditioning	PC	4	JA112 JA113	Performed on surface mount devices only. PC performed before THB, AC and TC stresses. It is recommended that JA112 be performed to determine at what preconditioning level to perform in the actual preconditioning stress JA113. Delamination from the die surface in A112 is acceptable if the device passes the subsequent reliability stress. The minimum, acceptable level for qualification is level 3. Any replacement of parts must be reported. TST before and after at room temperatures.
Temperature Humidity Bias	THB	5	JA101 JA110	PC before THB for surface mount devices, 85°C/85%RH/1000 hours or 130°C/85%RH/72 hours (HAST). TST before and after THB at room and hot temperatures.
Autoclave	AC	6	JA102	PC before AC for surface mount devices, 121°C/15psig/196 hours, TST before and after AC at room temperature.
Temperature Cycling	TC	7	JA104 (See Appendix 3 for package opening procedure)	PC before TC for surface mount devices, condition C (-65°C to 150°C) for 500 cycles or (-50°C to 150°C) for 1000 cycles, TST before and after TC at hot temperature. Three gram-force bond pull strength (BPS) after decap on five parts from one lot on corner bonds (2 bonds per corner), and one mid-bond per side.
Power Temperature Cycling	PTC	8	JA105	Test is performed only on devices with maximum rated power $\geq$ 1 watt and $\Delta T \geq 40$°C; -40°C to 125°C, 1000 cycles, TST before and after PTC at room and hot temperatures.
Mechanical Shock	MS	9	M2002	Y1 plane only, 5 pulses, 0.5 msec duration, 1500g peak acceleration. TST after CA.
Vibration Variable Frequency	VVF10	10	M2007	20Hz to 20KHz to 20Hz (logarithmic variation) in >4 minutes, 4x in each orientation, 50g peak acceleration. TST after CA.
Constant Acceleration	CA	11	M2001	Y1 plane only, 30K g-force for <40 pin packages, 20K g-force for 40 pins and greater. TST at room temperature.
Gross/Fine Leak	GFL	12	M1014	Any single-specified fine test followed by any single-specified gross test.
External Visual	EV	13	M2009	
Physical Dimensions	PD	14	JB100	See applicable JEDEC standard outline and individual device spec for significant dimensions and tolerances.
Lead Integrity	LI	15	JD105	Not required for surface mount devices.
Lid Torque	LT	16	M2024	
Bond Pull Strength	BPS	17	M2011	Condition C or D, Pre or Post Mold.

TABLE 3.3-2: TABLE OF METHODS REFERENCED (CONT'D)

Stress	Abrv	#	Reference	Additional Requirements
Bond Shear	BS	18	CDF-AEC-Q100-001	See CDF-AEC-Q100 Rev-A for details on the acceptance criteria and how to perform the test.
Die Shear Strength	DSS	19	M2019	For Ceramic Devices only
Electrostatic Discharge	ESD	20	CDF-AEC-Q100-002,-003	See CDF-AEC-Q100 Rev-A for details on how to perform test. TST after LV at room and hot temperature
Latch-up	LU	21	CDF-AEC-Q100-004	See CDF-AEC-Q100 Rev-A for details on how to perform test. TST after LV at room and hot temperature
Internal Water Vapor	IWV	22	M1018	
Solderability	SD	23	JB102	If burn-in screening is performed on the device, samples for SD must first undergo burn-in. Perform 8 hour steam aging prior to testing (1 hour for AV-plated leads)
E^2 PROM Data: Endurance Test Detention Test	ET	24	CDF-AEC Q100-005	For devices that contain E^2 PROM devices only. TST before and after at room and hot temperatures. This test does not replace other stress tests.
Early Life Failure Rate	ELFR	25	JA108	T_a = 125°C for 48 hours, or 150°C for 24 hours, performed after standard post-production flow unless supplier can demonstrate low initial failure rate (as agreed to by the user). Generic data is applicable. TST before and after at room and hot temperatures.
Electro-Thermally Induced Gate Leakage Test	GL	26	CDF-AEC-Q100-006	TST before and after at room temperature.
Electrical Distributions	ED	27	User or supplier specification	Supplier and user to mutually agree upon electrical parameters to be measured.

Legend for Tables 1 and 2

Note:	H	Required for hermetic packaged devices only.
	P	Required for plastic packaged devices only.
	N	Nondestructive test, devices can be used to populate other tests or they can be used for production.
	D	Destructive test, devices are not to be reused for qualification or production.
	S	Required for surface mount devices only.
	G	Generic data allowed. See Section 2.3
Methods:	M	MIL-STD-883, the most current revision and notice.
	J	JEDEC JESD22, the most current method.
	#	Number of the attached procedure

* All electrical testing before and after the qualification stresses are performed to the limits of the individual device specification in temperature and limit value.

** The number of lots required for qualification testing will depend on the amount and usefulness of generic data on the part or part family to be qualified, see CDF-AEC-Q100 Rev-A.

The remainder of the CDF-AEC-Q100 Rev-A document defines technology/component identification, change control, qualification family, assembly process and manufacturing site requirements.

The guideline CDF-AEC-A100 (draft) is the implementation of the Chrysler, Ford and General Motors QS-9000 Quality System Assessment for suppliers of Automotive grade semiconductor parts. The assessment is intended to evaluate:

- Design methodology
- Design validation
- Process capability and controls
- Environmental test facilities
- Failure analysis and corrective action
- Customer satisfaction

The following documents are referenced for use:

<u>Chrysler/Ford/General Motors</u>

QS-9000
Quality System Assessment
Fundamental Statistical Process Control (SPC)
Measurement Systems Analysis Reference Manual
The Production Part Approval Process (PPAP)
Failure Mode and Effects Analysis (FMEA)
Advanced Product Quality Planning and Control Plan Reference Manual (AQP)
Problem Resolution and Reporting (PR&R)

<u>Automotive Electronics Council</u>

CDF-AEC-Q100 Stress Test Qualification for Automotive-Grade Integrated Circuits

CDF-AEC-Q101 Stress Test Qualification for Automotive-Grade Discrete Semiconductors (Pending)

The remainder of the CDF-AEC-Q100 draft document contains questions and rationale to assist auditors and vendors.

4.0 PEM EVALUATION PROCEDURES

4.1 Thin Small-Outline Packages (TSOP)

The continuing evolution of the electronics industry has resulted not only in the increased miniaturization of semiconductor devices, but also in the reduction in the size of the microelectronic packages and carrier assemblies which contain them. Reliability concerns for small outline packages (SOP) are inherently different than those of the more traditional dual in-line (DIP) and chip carrier packages. Innovative approaches to packaging design have been necessary to meet the demands for low profile devices in numerous applications, including Personal Computer Memory Card International Association (PCMCIA) interface cards. The use of thin small outline package (TSOP) devices (with a nominal package height of 1.25 mm, package-to-board clearance of less than 0.05 mm and lead pitches in the range of 0.5 to 1.25 mm) mounted on thin carriers is the appropriate design solution for miniaturization, or where there may be restrictive weight constraints, within what are currently the standard surface mount technology (SMT) assembly processes. A TSOP bibliography is included in Section 4.5.

Two types of TSOP devices are available, and their dimensions are an Electronic Industries Association of Japan (EIAJ) standard. Type I packages have leads which emanate from the short dimension of the rectangular package, and have typical lead pitches of ≤ 0.5 mm. Lead count on current Type I TSOP packages varies from 20 to 32. Type II leads emanate from the long dimension of the package. Lead pitch for Type II devices are typically 0.8 mm or 1.27 mm. Lead counts for the Type II TSOP configuration vary from 20 to 44. The lead thickness for both package types is 0.12 mm.

Numerous factors affecting assembly reliability have been identified in the literature, covering components, carrier assemblies, card cleanliness, and the assembly process itself. The generic factors to be considered for plastic encapsulated devices include (1) the moisture absorption characteristics of the plastic, (2) the level of chemical contaminants in the plastic, (3) the ability of the plastic to adhere to the lead frame, (4) the lead frame design, (5) CTE matching, (6) mechanical compatibility between the plastic and the chip, (7) chip-surface passivation, and (8) stresses in the plastic as it hardens after molding. Table 4.1-1, compiled from a paper by Viswanadham, Stennet, Emerick and Haggett of IBM, provides an overview of these considerations for TSOP devices.

TABLE 4.1-1: OVERVIEW OF TSOP ASSEMBLY RELIABILITY CONSIDERATIONS

Level	Reliability Considerations
Component	• Package size to chip ratio is close to one • Due to package thinness, the amount of plastic in a TSOP is small • Ratio of volume of molding compound to volume of silicon is small (TCE of TSOP closer to that of silicon) • Greater TCE mismatch between TSOP and glass epoxy FR4 substrate than for PQFP/FR4 interface. • Relaxation of TCE mismatch in solder occurs through creep (plastic deformation in bulk solder). • Low cycle fatigue fractures result from cumulative damage of creep • Low profile (short lead height) of TSOP results in stiffer, less resilient package than longer lead PQFP. • Lead material affects lead compliance. • Copper alloy lead frames (many PQFPs) are more ductile than TSOP iron-nickel alloys. • Smaller cross-sectional areas, longer leads and more ductile materials increase lead compliance. • Moisture permeability into the package is greater if TSOPs are not shipped in dry packages or stored in low humidity environments. • During solder reflow, absorbed moisture egresses at an explosive rate to induce package cracking (POPCORN effect). • Package cracking can occur during component rework. • Sn/Pb lead plating integrity is important, where lead forming can deform the plating, introduce stresses in the plating, generate microcracks, facilitate humidity/corrosive gas permeation to the interface, and oxidize the soldering surface (poor solder wetting). • Lead noncoplanarity variations alter the shape of the solder joints. • Conventional criteria for lead foot above the pad, acceptable for other SMT components, are unsatisfactory for low standoff thin packages with low TCE.
Carrier	• Utilization of thin (<0.015") carriers poses challenges to assembly reliability & manufacturability. • Carrier protective coating thickness must be minimized (no thicker than the surface copper) due to TCE low standoff (often under 0.002"). • Too thick a coating results in non-wetting or elongated solder joints. • Warpage of the carrier due to its thinness, cross-section, moisture absorption/desorption and reflow process has a negative yield impact. • Pad dimension optimization is an important aspect of the process. • Long pads extending into underside of TSOP device are detrimental to solder joint reliability. • Excess solder paste on long pads increases wicking potential. • Ensure adequate pad area beyond lead footprint to provide side and heel fillets. Lack of these fillets produces weaker solder joints, particularly in TSOP II modules (tortional forces during thermal cycling). • Lack of adequate TSOP lead heel and toe fillets results in weak solder joints.
Card Cleanliness	• Assemblies contaminated with fibrous materials (i.e., cotton, polyester, rayon) embedded in the solder joints can absorb moisture to facilitate dendrite growth, short adjacent leads, or reduce insulation resistance below acceptable levels. • Assemblies should meet criterion of: - 1 microgram/cm^2 NaCl equivalent for surface cleanliness - Surface insulation resistance of 300 hours at 50°C and 80% RH with m-Ohms resistance requirement after 24 hour dry out.

TABLE 4.1-1: OVERVIEW OF TSOP ASSEMBLY RELIABILITY CONSIDERATIONS (CONT'D)

Level	Reliability Considerations
Assembly Process	• Majority of TSOP applications use basic SMT, Double Sided Double Pass (DSDP), or DSDP with Partial Wave Solder assembly process. Screening: - Thin stencils (approx. 4-6 mils) are recommended. - Thinner stencil plus a larger opening (i.e. better aspect ratio) provides more consistent solder volume for screening ≤ 0.5mm pitch. - Thinner stencils are more prone to handling damage. - Use of thinner stencils with standard thickness or 50 mil pitch devices should be analyzed to avoid insufficient solder in their joints. - Provide as much support as possible to carrier backside to avoid smearing, scooping or other damage to the solder paste deposit. Placement: - Industry standard placement tooling can be used on TSOP devices. - Requirement for fiducials at component site must be analyzed due to areas used for fiducials. - Suitability of shared card or site fiducials by TSOP devices should be investigated. - Support of carrier/assembly is required to ensure device alignment on the paste. - Minimize the screen to placement time to obtain the highest quality results. Reflow: - Do not elevate reflow temperatures above the minimum required to get a good solder joint (moisture sensitivity failure mechanisms). - Keep TSOPs in a low humidity environment. - Do not expose TSOPs to ambient temperatures for long periods of time prior to placement and reflow. Cleaning: - Use surface insulation testing to assess acceptability of the existing aqueous cleaning process when required by the solder paste operation. - Ionic contaminants under low standoff TSOP devices can lead to metal migration or dendritic growth. - If electronic card assembly is performed in card format, use fixturing to stabilize during pressurized cleaning.

Companies such as IBM, AT&T Bell Laboratories, Intel Corporation and Hewlett Packard have performed extensive reliability evaluations of TSOP packages, primarily focusing on package lead solder joint failure modes and mechanisms. An overview of these efforts is shown in Table 4.1-2. The subscripts next to the corporate name refer to the bibliographic reference from the TSOP Bibliography provided in Section 4.5.

TABLE 4.1-2: TSOP PACKAGE EVALUATION

IBM_{43}	• Performed finite element modeling, surface insulation resistance testing and accelerated thermal cycling testing to evaluate assembly reliability of TSOP devices. • Effort aimed at understanding strains on solder joints and their dependence on physical properties of the component materials, stand-off, lead height and positioning of the modules on the cards. • Evaluate the effect of an encapsulant on the solder joints and the degree of improvement attainable through encapsulation.	• TSOP I vs. TSOP II package assembly reliability is attributed to differences in lead stiffness and shearing incidence angle with more torsional forces on TSOP II leads. • Thick card assemblies are less reliable than thin card assemblies. • Double sided assemblies appear to be less reliable than single sided assemblies. • TSOP devices are less reliable (fatigue life) than POFP devices. Absence of side fillet raises plastic strain from 1.85% to 2.5%. • Absence of toe fillet reduces reliability by as much as two times. • Lead-on-chip (LOC) designs provide lead height enhancements and increase lead compliancy (increase solder joint reliability).
IBM_{13}	• Experimental work on both standard 0.062" thick FR4 cards, and also thin cards with 0.015" nominal thickness. • Demonstrate the improvements in TSOP reliability when the solder joints are encapsulated. • Encapsulant used is commercially available glass filled epoxy resin.	• Improvement in the encapsulated TSOP solder joint is attributed to a dramatic change in the failure mechanism as compared with an unencapsulated package. • Bare lead solder joint fails from highly localized fatigue strains at heel of TSOP. • Encapsulated lead eliminates localized fatigue strains on solder joint. Strains are uniformly dispersed over the encapsulated area between card L~ component. • Marginal solder joints of TSOP unencapsulated leads failed at less than 150 ATC. • Good solder joints of TSOP unencapsulated leads were electrically/structurally unsound at 500 cycles. • Encapsulated TSOP cells showed no failures or indications of changes within the solder joints at > 3000 cycles.
AT&T/Kohl $Group_{35}$	• Evaluation of attachment reliability of TSOPs for telecommunications applications. • TSOPs containing Alloy 42 or copper leadframes were evaluated on FR4 substrates using tin-lead eutectic.	• Both Alloy 42 and copper leadframed TSOPs failed ATC by complete side separation from the PWB. • Predictive modeling showed that TSOP solder joint life is 5 times longer with copper than with Alloy 42 leadframes. • In mild conditions and a short design life, Alloy 42 leaded TSOPs may be reliable for some consumer and industrial applications. • For copper leaded TSOPs, an unacceptable 3% failure probability was extrapolated for the intended 20-year design life (35°C to 70°C thermal cycling, 1 cycle/day, PWB CTE = 19ppm/°C.

TABLE 4.1-2: TSOP PACKAGE EVALUATION (CONT'D)

AT&T/Intel Corp36	• Evaluation of long term surface mount attachment reliability of TSOPs using thermal cycling as an acceleration method. • Visual inspections, pull strength and scanning electron microscopy were used to characterize the solder joints. • Solder plating, lead wetting and aging characteristics were evaluated.	• Failure during thermal cycling was primarily caused by CTE mismatch between the TSOP and the PWB. • Cracks in TSOP solder joints propagated rapidly to separate the package side from the board. • Thermal cycling test results predicted high attachment failure probability for the 20 year design life. • TSOPs may perform reliably on thin flexible boards, on low expansion boards, on products with short design life, or on products in thermally controlled environments. • TSOP component design and materials choices provided a robust, moisture insensitive package with attachment reliability problems (CTE mismatch). • Improving solder fatigue performance by switching to copper leadframes may result in moisture sensitivity and die stress problems.
Hewlett-Packard/ Intel24	• A study of the reliability of 0.5 mm pitch, 32-pin TSOP solder joints by experimental temperature cycling and 3-D nonlinear finite element analysis. • Failure analysis has been performed using scanning electron microscopy (SEM) and optical methods. • Presents a quantitative comparison between TSOP Type I and Type II solder joints.	• Provides charts for life distribution, reliability function and failure rate of the 32-pin TSOP solder joints (1 cycle/day, 0°C to 85°C). • Ninety-nine percent of TSOP solder joints will survive 63,300 hours (7.2 years). • Fifty percent failure point occurred at 163,900 hours (18.7 years). • The location of the solder joint failures was randomly distributed. • Plastic strains in the solder joint were calculated. Average thermal fatigue life was 4,160 daily cycles (11.4 years). • The predicted average thermal fatigue life was 39% less than the test result at 50% failures (analyzed at the corner solder joint). • The thermal fatigue life of TSOP Type I solder joints was better than Type II. To be comparable, Type II lead widths must be reduced from 0.4 mm to 0.2 mm.
Hewlett-Packard/ Intel28	• Considers the advantages of TSOP with copper leads by comparing (1) the calculated stress & strain in the solder joints with that of the TSOP with Alloy 42 lead frames, and (2) the experimental life distribution with that of the TSOP with Alloy 42 leads. • The disadvantages of TSOP with copper leads are shown by considering the technology limitations & manufacturing constraints.	• Local thermal expansion mismatch between the copper lead and 63/37 SnPb solder is less than that between the Alloy 42 lead and the solder. • Global mismatch between copper lead frame TSOP and FR4 PCB is smaller than the Alloy 42 equivalent. • Average thermal fatigue life of copper leaded TSOP solder joints is predicted to be 53% better than that of Alloy 42 leaded TSOPs (based on effective stress and cumulative effective plastic strain in the corner solder joint). • Thermal characteristic life of the copper leaded TSOP solder joints is 36% better than that of the Alloy 42 leaded TSOPs (based on thermal cycling tests and statistical analysis). • Disadvantages of TSOPs with copper leads include the internal thermal expansion mismatch within the package, the moisture sensitivity that may cause popcorn cracking, and the loss of rigidity that leads to handling difficulties, warped lead frames, bent leads, and difficulty in controlling coplanarity.

TABLE 4.1-2: TSOP PACKAGE EVALUATION (CONT'D)

IBM30	• Uses Finite Element modeling techniques to determine solder joint reliability for encapsulated and unencapsulated TSOP assemblies. • Analyzes the effects of encapsulant defects, mounting schemes, and lead frame materials on solder joint reliability.	• Finite element modeling results are consistent with ATC and Laser Morie Interferometry tests: - Maximum equivalent plastic strain (EPEQ) occurs at the corner joint for unencapsulated cases. - Lead frame materials do not affect the locations of the maximum EPEQ. - Solder joints for single-sided assembly are approx. 2.5X more reliable than for double-sided assemblies. - Copper lead frames provide at least 2X reliability improvement compared to Alloy 42 lead frames. - Maximum EPEQs shift from the heel fillet for the unencapsulated cases to the toe or foot under the lead for encapsulated leads. The EPEQs are always reduced for encapsulated configurations. - Maximum EPEQs shift back to the heel fillet and the EPEQ magnitude is higher than that of the unencapsulated case, if no encapsulant exists on the entire lead for the fully encapsulated case (jeopardizes solder joint reliability). - Voids in encapsulant may produce higher reliability risk (further studies needed). • Solder joint reliability can be improved by: - Thinner card assemblies - Use of single-sided assemblies - Copper lead frames - More flexible leads - Use of encapsulation • Despite implemented improvements, unencapsulated solder joints with poor fillet formation exhibit early cracking. • Solder joints survive > 5000 ATC cycles for encapsulated TSOPs.

4.2 Internal Analysis Using Scanning Acoustic Microscopy

Acoustic micro-imaging methods include through transmission and reflection (pulse echoe) techniques which are highly sensitive to material discontinuities. Various usage modes may be selected to observe plastic package internal irregularities without physical alteration.

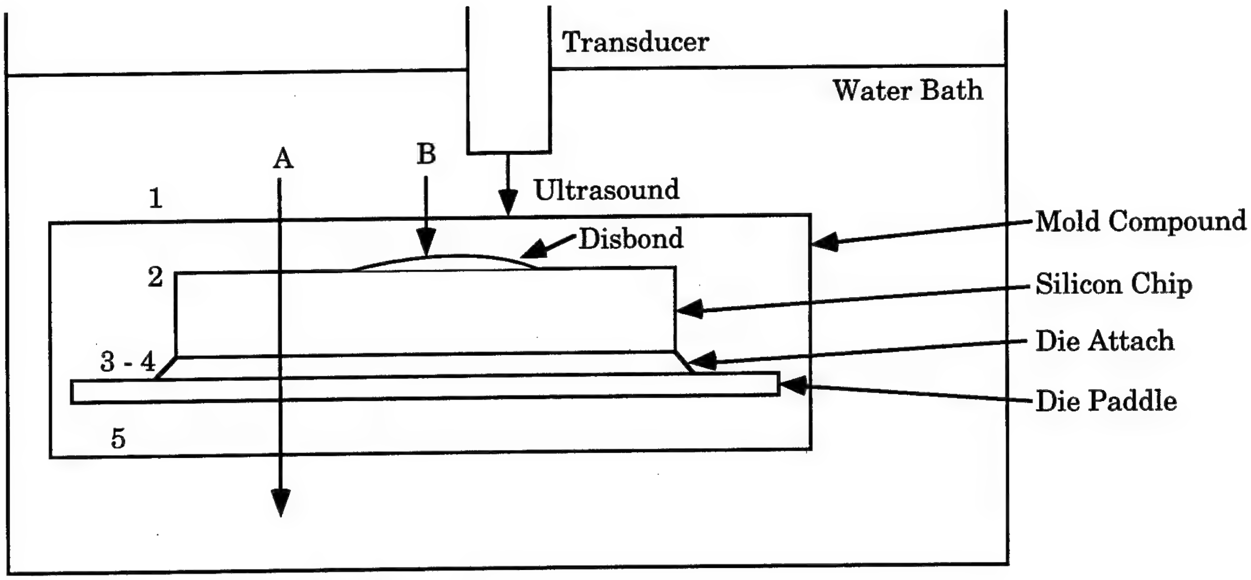
The C-Mode Scanning Acoustic Microscope (C-SAM) is a nondestructive testing instrument for analyzing samples, and produces high resolution ultrasonic images of internal defects. The C-SAM is used for laboratory testing and quality control of devices, and material property characterization of ceramics, metals, polymers and other composites. It allows for the identification of internal

features beneath a sample's surface one plane at a time, enabling the discovery of hidden defects, such as poor bonding, delamination, voids and cracks.

In C-SAM analysis, the material or device to be examined is submerged in a coupling fluid, such as water or alcohol. Precise images are generated by rapidly scanning a piezoelectric transducer over the sample at a focused depth or interface. Short pulses of acoustic (ultrasound) energy, 10-150 Mhz, are produced by the transducer. The higher frequencies, depending on the material being analyzed, produce higher resolution images. Ultrasound is reflected and transmitted at the interfaces between dissimilar materials. Echoes received by the transducer are analyzed on an oscilloscope and a CRT display. The echo amplitude and polarity are dependent on the material property (density and acoustic velocity) differences encountered at the interface and provide key information for performing the analysis. Comparisons of the amplitude and polarity provide the analyst information to distinguish between voids, delaminations, contaminants and good interfaces.

Plastic packages are typically analyzed using transducer frequencies between 10-30 MHZ depending on the thickness of the package. Thick plastic packages result in attenuation loss of the ultrasound and difficulty in using the higher frequencies. The image in Figure 4.2-1 is a schematic of a cross-section of a plastic package. Lines A and B are two ultrasound paths with the oscilloscope traces shown below. When ultrasound travels from a low to a high acoustic impedance material, a positive echo results and vice versa for a high to low acoustic impedance material, a positive echo results and vice versa for a high to low acoustic impedance interface. In trace A, the ultrasound travels from water to mold compound which results in a positive echo. The next interface, mold compound/silicon die, also results in a positive echo. If we compare the second echoes from trace A and B, we notice a difference in the polarity. The second echo of trace B is negative due to the phase change of the ultrasound at the mold compound/disbond interface on the surface of the silicon die. Echoes 2, 3, and 4 for trace A are close together due to the acoustic velocity in silicon and echo 5 is small considering most of the ultrasound has been reflected at the previous interfaces. There aren't any echoes on trace B after echo 2 due to ultrasound being virtually impenetrable through a vacuum. Images in color or monochrome

are produced from the amplitude and polarity of these traces and viewed on a CRT display.



Approximate Acoustic Impedance of Materials in Plastic Packages

Material	$Kg/M^2.S$
Water	1.4
Mold Compound	6.7
Air	0.0
Silicon	19.7
Die Attach	5.1
Copper	41.8

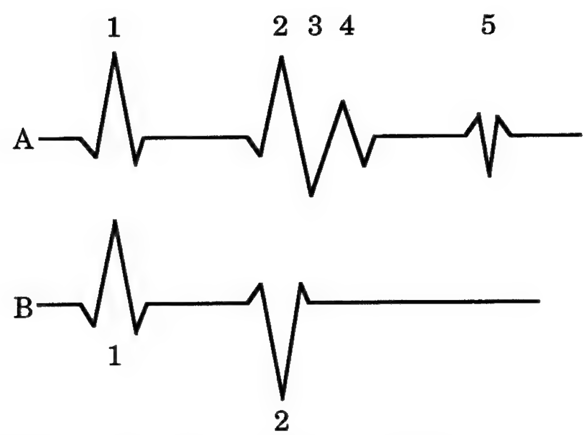


FIGURE 4.2-1: CROSS SECTION SCHEMATIC OF A PEM DURING C-SAM

4.3 Destructive Physical Analysis (DPA) Failure Analysis (FA) Procedure for PEMs

A need exists for a DPA procedure to assess PEM design quality through a construction analysis and to provide baseline information for failure analysis. The Oneida Research Services, Inc. (ORS) proposed PEM DPA flow was used in preparing this section.

The existing DPA procedure, Test Method 5009 of MIL-STD-883, contains the following traditional testing/criteria for hermetic packaging:

External Visual	Radiography
Hermeticity*	Internal Water Vapor*
Internal Visual	Bond Strength
SEM of Metallization Configuration	Die Shear

The previous tests marked with an asterisk are not required for PEMs. However, the procedure lacks package/material analysis and the die level inspection is inadequate.

The following listing describes a proposed DPA flow for PEMs:

External Visual	Die Shear
Radiography	Internal Visual
*Acoustic Microscopy	*Inspection of Passivation
*Dye Penetrant	*Passivation Integrity Test
*Decapsulation of Plastic	SEM Inspection
*Package Cross-Section	*Bond Pad, Metallization & Contact Inspection
Bond Strength	*Level Cross-Section

The tests added to the PEM DPA procedure are identified by an asterisk and their features are included in Table 4.3-1.

A weak point in this procedure is the passivation analysis. The passivation test included is Test Method 2021 of MIL-STD-883 "Glassivation Layer Integrity". This test is directed at identifying processes and materials related to glass layer defects which result in localized contamination build up and loss of the advantage given to properly glassivated devices in terms of electromigration behavior at elevated temperature and current density. A test/procedure to ensure a defect free (pinholes, cracks) passivation is needed.

DPA is a valuable vendor and component selection tool which can be used to ensure continued product quality, performance and reliability. The construction analysis performed can also be used as a baseline for future analyses related to product acceptance or the evaluation of process changes.

TABLE 4.3-1: PEM DPA TESTS

Acoustic Microscopy • Screen Packages for Voids/Cracks • Assess Leadframe/Encapsulant Bond • Evaluate Encapsulant/Die Adhesion • Inspect Die Attach Region
Dye Penetrant and Package Cross-Section • Test "Hermeticity" of Plastic Packages • Characterize Molding Compound • Inspect Wire Bonds • Examine Die Attach
Decapsulation of Plastic Encapsulated ICs • Nitric and Sulfuric Acid Etch • Plasma Etch • Solvent Systems • Mechanical Methods
Inspection of Passivation • Qualitative EDX Analysis • SEM Inspection of Passivation • Glassivation Integrity Test
Die Level Cross-Section • Detail Passivation Thickness and Coverage • Measure Metallization Thickness and Coverage • Monitor Manufacturing Processes
Bond Pad, Metallization and Contact Inspection • Inspect Bond Site for Damage - Cratering - Cracking - Pitting • Inspect Vias and Contacts for: - Silicon Nodules/Precipitates - Edge Definition - Wall Profile • Metallization - Cracking - Other Physical Damage

4.4 PEM Decapsulation Procedure

Discussions held with PEM users identified a need for an acceptable PEM decapsulation procedure for use during failure analysis and DPA. The following procedure, contained in Appendix 3 of CDF-AEC-Q100 Rev-A and intended for use to provide acceptable wire bonds for testing, describes a common procedure used for decapsulation.

4.4.1 Purpose

The purpose of this method is to define a guideline for non-destructive decapsulation of plastic packaged parts so that reliable wire pull or bond shear results will be obtained. This method is intended for use in opening plastic packaged parts to perform wire pull testing after temperature cycle testing, or for bond shear testing.

4.4.2 Materials and Equipment

Etchants

Various chemical strippers and acids may be used to open the package, dependent on experience with these materials in removing plastic molding compounds. Red Fuming Nitric Acid has demonstrated that it can perform this function very well, but other materials may be utilized if they have shown a low probability for damaging the bond pad material.

Plasma Strippers

Various suitable plasma stripping equipment can be utilized to remove the plastic package material.

4.4.3 Procedure

Using a suitable end mill type tool or dental drill, create a small impression just a little larger than the chip in the top of the plastic package. The depth of the impression should be as deep as practical without damaging the loop in the bond wires.

Using a suitable chemical etchant or plasma etcher, remove the plastic material from the surface of the die, exposing the die bond pad, the loop in the bond wire, and at least 75% of the bond wire length. Do not expose the wire bond at the lead frame (these bonds are frequently made to a silver plated area and many chemical etchants will quickly degrade this bond, making wire pull testing impossible).

Using suitable magnification, inspect the bond pad areas on the chip to determine if the package removal process has significantly attacked the bond pad metallization. If a bond pad shows areas of missing metallization, the pad has been degraded and should not be used for bond shear or wire pull testing. Bond pads that do not show evidence of attack can be used for wire bond testing.

4.5 Bibliography for TSOP Technology

1. "General Rules for the Preparation of Outline Drawings of Integrated Circuits, Thin Small Outline Packages (Type 1), (TSOP 1)", EIAJ ED-7402-3, The Electronic Industries Association of Japan, April, 1991.

2. "Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments", IPC-SM-785, The Institute for Interconnecting and Packaging Electronic Circuits, November, 1992.

3. "Package/Module Outlines and Dimensions", Packaging, Intel Corporation, 1991, p. 2-113

4. "Requirements for Soldered Electrical and Electronic Assemblies", ANSVJ-STD-001, Section 9.2.6.2, Joint Standard developed by the EIA and IPC, September, 1991.

5. "Solder Joint Reliability", Thin Small Outline Package Packaging Guide, Section 6-7, Intel Corporation, 1992, p. 6-3.

6. Alexander, P.; Bello, D.; "The Shape of the Future", Circuits Manufacturing, 1988, pg. 80.

7. Bonnell, R.; Castello, C.; Stennett, M.; "Design for Manufacturability - Concurrent Engineering of Design and Assembly Process", Proceedings of the Technical Program 1992 NEPCON.

8. Bonnell, R.; Castello, C.; Stennett, M.; "Double Sided Double Reflow with Partial Wave Solder Assembly Process", ISHM 1992 Proceedings, pp. 285-288.

9. Clech, J.P.; Manock, J.C.; Noctor, D.M.; et. al.; "A Comprehensive Surface Mount Reliability (CSMR) Model Covering Several Generations of Packaging and Assembly Technology", Proceedings of the 43rd ECTC, June, 1993.

10. Clech, J.P.; Engelmaier, W.; Kotlowitz, R.W.; Augis, J.A.; "Surface Mount Solder Attachment Reliability Figures of Merit - Design for Reliability' Tools", Proceedings of the SMART V Conference, Technical Paper SMT V-48, January, 1989.

11. Cohen, M.; Cobert, T.; Mauritz, K.; et. al., "TSOPs Make IC DRAM Cards Possible with Conventional Technology", Microelectronics/Manufacturing Technology, Vol. 14, No. 9, Sept. 1991, pp. 19-21.

12. Corbin, J.; Villarreal, J.; "Reliability of TSOP Devices", IBM Internal Publication, Dec. 1991.

13. Emerick, Alan; Ellerson, James; McCreary, Jack; et. al., "Enhancement of TSOP Solder Joint Reliability Using Encapsulation", Proceedings of the 43rd ECTC, June, 1993, 0569-5503/93/0000-0187, pp. 187-192.

14. Engelmaier, W., "The Use Environments of Electronic Assemblies and Their Impact on Surface Mount Solder Attachment Reliability", SMT Seminar Proceedings, Austin, TX, July, 1991.

15. Engelmaier, W., "Generic Reliability Figures of Merit Design Tools for Surface Mount Solder Attachment", IEEE Trans. CHMT, 15 [6], December 1992.

16. Gecius, J., "PCMCIA - An Emerging Packaging Technology for Portable Computers", Proceedings of the Technical Program 1993 NEPCON, pg. 733

17. Golwalkar, S., "Solutions to Moisture Resistance Degradation of Plastic Surface Mount Components", in Thermal Stresses and Strains in Microelectronic Packaging, ed. by J.H. Lau, Van Nostrand Reinhold, New York, 1993.

18. Golwalkar, S.; Boysan, P.; Foehringer, R.; Jacobs, J.; "Moisture Sensitivity of Thin Small Outline Packages", IEEE Proceedings of the 41st Electronic Components & Technology Conference, May, 1991, pp. 745-749.

19. Guo, Y.; Han, B.; Caletka, D.V.; "Experimental/Numerical Evaluation of TSOP Solder Joint Strain", To Be Published.

20. Johnson ,T., "Memory Cards and Traditional Mobile Computing Architecture", Memory Card, Vol. 2, No. 1, January, 1992, pg. 20.

21. Kim, S., "The Role of Plastic Package Adhesion in IC Performance", IEEE Proceedings of the 41st Electronic Components & Technology Conference, May, 1991, pp. 750-758.

22. Kotlowitz, R.W., "Comparative Compliance of Representative Lead Designs for Surface Mounted Components", IEEE Trans. CHMT, 12 [4], December 1989, pp. 431-448.

23. Lau, J.; Golwalkar, S.; Rice, D., et. al., "Experimental and Analytical Studies of 28-Pin Thin Small Outline Package (TSOP) Solder Joint Reliability", ASME Winter Meeting, 1991, pg. 2.

24. Lau, J.; Golwalkar, S.; Boysan, P.; et. al.; "Solder Joint Reliability of a Thin Small Outline Package (TSOP)", Proceedings of the 42nd ECTC, May, 1992.

25. Lau, J.H.; Powers, L.; Baker, J.; et. al.; "Solder Joint Reliability of Fine Pitch Surface Mount Technology Assemblies", IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol. 13, Sept. 1990, pp. 534-544.

26. Lau, J.H.; Keely, C.A.; "Dynamic Characterization of Surface Mount Component Leads for Solder Joint Inspection", IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol. 12, No. 4, December, 1989, pp. 594-602.

27. Lau, J.H.; Rice, D.W.; "Solder Joint Fatigue in Surface Mount Technology: State of the Art", Solid State Technology, Vol. 28, October, 1985, pp. 91-104.

28. Lau, J.H.; Golwalkar, S.; Erasmus, S.; "Advantages and Disadvantages of Thin Small Outline Packages (TSOP) with Copper Gull-Wing Leads", EEP-Vol. 4-2, Advances in Electronic Packaging, ASME, 1993, pp. 1119-1126.

29. Lau, J.H., "Solder Joint Reliability: Theory and Applications", Van Nostrand Reinhold, New York, 1991.

30. Lee, J.; Caletka, D.; "TSOP Encapsulation Reliability Modeling", EEP-Vol. 4-2 Advances in Electronic Packaging, ASME 1993, pp. 1135-1141.

31. Lowe, H., Ford, W., "Overview of PCMCIA Packaging and Card Assembly Process", Proceedings of the Technical Program 1993 NEPCON West Conference, pg. 737.

32. Lyn, R.J., "Encapsulation of PCMCIA Assemblies - An Overview", Proceedings of the Technical Program of 1993 NEPCON West Conference, pg. 743.

33. Moore, T.M.; McKenna, R.; Kelsall, S.J.; "Correlation of Surface Mount Plastic Package Reliability Testing to Nondestructive Inspection by Scanning Acoustic Microscopy", IEEE Proceedings of the 29th International Reliability Physics Symposium, April, 1991, pp. 160-166 .

34. Murakami, G.; Tsubosaki, K.; Otsuka, K.; Nishi, K.; "Thinner, High Density, High Speed Packaging Technology", The Hitachi Hyoron, December 1990, pg. 51 35. Noctor, D.; Clech, J.P.; "Accelerated Testing and Predictive Modeling of the Attachment Reliability of Alloy 42 and Copper Leaded TSOPs", Proceedings of the Technical Program 1993 NEPCON East Conference, 13 pgs.

36. Noctor, D.; Bader, F.E.; Viera, A.P.; et. al.; "Attachment Reliability Evaluation and Failure Analysis of Thin Small Outline Packages (TSOPs)", Proceedings of the 43rd ECTC, 0569-5503/93/0000-0187, June, 1993, pp. 54-61.

37. Noctor, D., Data presented to IPC Task Group on "Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments", IPC-SM-785, August, 1992.

38. Omi, S.; Fujita, K.; Tsuda, T.; Maeda, T.; "Causes of Cracks in SMD and Type Specific Remedies", IEEE Component Hybrid and Manufacturing Technology, 1991, pg. 766.

39. Reimer, D.E., "Prediction of Temperature Cycling Life for SMT Solder Joint on TCE-Mismatched Substrate", Proceedings of the IEEE Electronic Components & Technology Conference, May, 1990, pp. 418-425.

40. Stennett, M.; et. al.; "Double Sided Two Pass Reflow SMT/PIH Assembly Process. IPC Proceedings, 1992.

41. Stennett, M.; Villarreal, J.; "Card Thickness Effect on TSOP Solder Joint Strain", IBM Internal Publication, June, 1991.

42. Suryanarayan, D.; Hsiao R.; Gall, T.P.; McCreary, J.M.; IEEE Transactions on Components, Hybrids and Manufacturing, Vol. 14, No. 1, January, 1991, pp. 218-223.

43. Viswanadham, P.; Stennett, M.; Emerick, A.; Haggett, R.; "Second Level Assembly and Reliability Aspect of Thin Small Outline Packages", Advances in Electronic Packaging, EEP Vol. 4-2, ASME 1993, pp. 1127-1134.

44. Viswanadham, P.; Coplin, D.; Emerick, A.; Haggett, R.; "Solder Joint Reliability of TSOPS - An Overview", Proceedings of the Electronic Components and Technology Conference", June, 1993, pg. 863.

45. Viswanadham, P., "Reliability Aspects of Fine Pitch Assembly", in Handbook of Fine Pitch Surface Mount Technology, ed. by J.H. Lau, Van Nostrand Reinhold, New York, 1993.

46. Watson, D.; Fleming, T.: "Determining the Reliability of Small Outline Packages", Electronic Packaging and Production, November, 1992, pp. 60-62.

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5.0 SUMMARY OF DATA COLLECTED

Data was collected on PEMs from a variety of sources in an attempt to characterize their reliability under a variety of test and use conditions. The following types of data were collected and analyzed: Field Operating, Highly Accelerated Stress Test (HAST), Autoclave, Life Test, 85°C/85% RH, High Temperature Storage, Temperature Cycling, and Failure Mode/Mechanism data. This section of the report presents a summary of the data collected in the above listed categories, and Section 6 of this report utilizes this data to develop a reliability prediction model for PEMs.

The data presented is a summary of that contained in the Reliability Analysis Center (RAC) databases. Due to its volume, the detailed data will not be presented. There were, however, several criteria that were used to ensure that only good quality data was added to the RAC databases. In the case of field data, populations, part type, usage conditions, data collection time period, and number of failures were known prior to addition into the database. Additionally, all failures were confirmed to the extent that part replacement corrected the observed circuit failures.

5.1 Field Data

A summary of the field failure rate data collected is presented in Table 5.1-1 as a function of application environment and device type. All failure rate units are in failures per 10^6 operating part hours.

TABLE 5.1-1: SUMMARY OF FIELD RELIABILITY DATA

Device Type	Application		
	Ground Benign (G_B)	Commercial Airborne (A_I)	Automotive Underhood (G_M)
Linear	.0030	.054	.32
Digital SSI/MSI	.00097	.01	.11
Memory/Microprocessor	.0023	.14	.13

Each failure rate in this Table represents many individual parts. The airborne and automotive data were generated in the 1992 time frame. The failure rates for Ground Benign data were estimated by regressing the failure rate against a year for each generic category of component, and estimating the failure rate in 1992. By normalizing the data to 1992, it can be directly compared.

To give the reader a better understanding of the quantity of data comprising each source, Table 5-1.2 provides the total number of part hours and the total number of failures. The values provided for the ground benign category represent cumulative data taken from 1980 to 1992, with the majority of failures observed in the early years of that time period.

TABLE 5.1-2: QUALITY OF FIELD DATA COLLECTED

Application	Operating Hours	Number of Failures
Ground Benign	4.5×10^{11}	57,274
Automotive Underhood	8.0×10^{10}	18,830
Commercial Airborne	2.2×10^{9}	98

5.2 Highly Accelerated Stress Test (HAST) Data

All available HAST data was analyzed to determine the time-to-failure characteristics of PEMs when subjected to HAST testing. HAST testing is a test which subjects PEMs to high temperatures and high humidity levels simultaneously. A total of 99 data sets were available for this purpose, of which twenty contained data complete enough to perform a Weibull analysis. From this analysis, the characteristic lives (α) and shape parameters (β) were determined. Figures 5.2-1 and 5.2-2 contain histograms of the shape parameters (β) and characteristic lives (α), respectively.

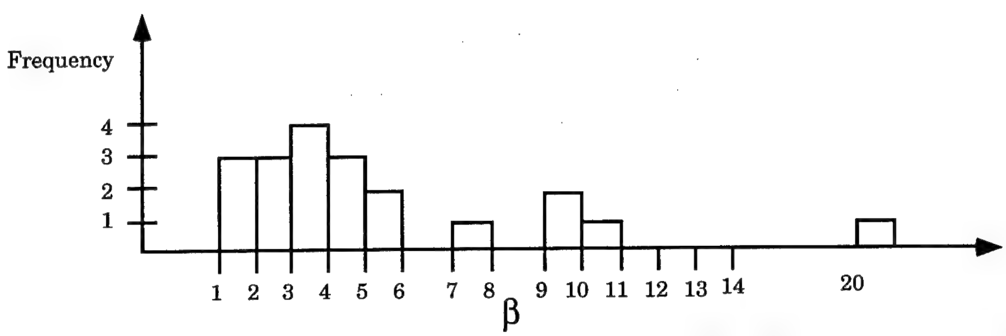

FIGURE 5.2-1: HISTOGRAM OF HAST WEIBULL SHAPE PARAMETERS (β)

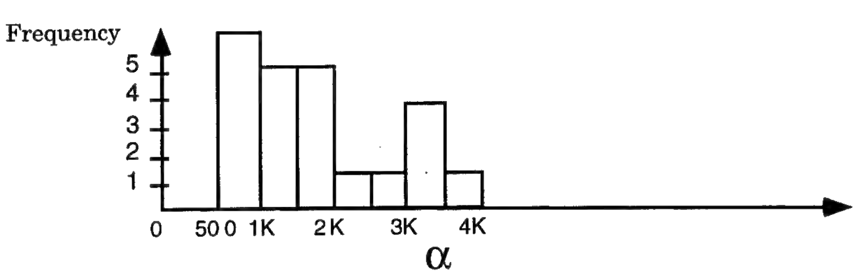

FIGURE 5.2-2: HISTOGRAM OF HAST WEIBULL CHARACTERISTIC LIVES (α)

Analysis of the shape parameter distribution yields a mean of approximately 4.5, excluding outliers. The characteristic lives of all 99 datasets were then approximated by assuming a $\beta = 4.5$, along with the highest percentage failure point available from each dataset. Table 5.2-1 presents a summary of this analysis and includes the reference from which the data was extracted, the time at which the maximum percent failure occurred, the maximum percent failure, temperature, relative humidity, and the estimated characteristic life.

TABLE 5.2-1: HAST RESULTS

Ref.	Time	% Fail	Temp.	RH	Estimated Characteristic Life (α)
26	750	28	130	85	961
26	1000	30	130	85	1265
2	400	0	140	85	-
2	400	28	140	85	512
2	400	36	140	85	481
2	400	0	140	85	-
2	400	64	140	85	400
2	700	0	140	85	-
2	500	76	140	85	463
2	700	4	140	85	1428
2	1500	52	140	85	1612
2	1600	40	140	85	1860
2	500	68	140	85	485
2	400	57	140	85	416
2	500	68	140	85	485
2	1500	50	140	85	1630
2	1600	40	140	85	1860
2	500	61	140	85	510
2	500	43	140	85	574
2	1000	50	140	85	1087
2	1400	40	140	85	1627
2	1600	23	140	85	2162
2	1200	27	140	85	1558
2	1600	23	140	85	2162
9	1600	42	145	85	1839
9	1600	32	145	85	1975
9	1600	18	145	85	2285
9	1600	7	145	85	2857
9	1100	90	145	85	916
9	1100	20	145	85	1527
9	1100	12	145	85	1746
9	1100	3	145	85	2391
13	500	85	130	85	434
13	350	35	130	85	426
13	2000	73	130	85	1886
13	1500	32	130	85	1851
13	4000	52	120	85	4301
13	2000	51	130	85	2173
16	1000	63	130	85	1000
16	1000	80	130	85	901
16	3000	0	130	85	-

TABLE 5.2-1: HAST RESULTS (CONT'D)

Ref.	Time	% Fail	Temp.	RH	Estimated Characteristic Life (α)
16	1000	37	130	85	1219
16	1000	30	130	85	1234
16	750	97	130	85	563
16	3000	3.3	130	85	6382
16	1500	93	130	85	1209
16	750	100	130	85	490
16	3000	0	130	85	-
16	1600	24	140	85	2133
16	700	100	145	85	457
16	1000	100	130	85	653
16	2300	100	130	85	1503
16	2300	100	140	85	1503
16	2300	100	130	85	1503
14	900	100	159	85	613
14	1000	36	159	85	1358
25	500	45	159	85	561
25	1000	35	159	85	1219
27	2000	4	85	85	4081
27	1000	7.7	105	85	1754
27	1500	5	115	75	2884
27	1500	2.3	115	85	3488
27	1000	10.4	115	95	1639
27	1000	44	125	85	1136
26	4000	6	130	85	7407
26	4000	0	130	85	-
26	4000	0	130	85	-
26	3000	50	130	85	3261
26	3000	15	130	85	4687
26	4000	0	130	85	-
26	4000	18	130	85	5714
26	4000	8	130	85	7017
26	4000	33	130	85	4938
9	300	10	140	85	491
9	700	100	145	85	457
9	1000	100	145	85	653
9	2400	100	145	85	1568
9	2400	100	145	85	1568
9	1400	100	145	85	915
9	5000	15	145	85	7462
9	5000	10	145	85	8196
9	5000	0	145	85	-
9	2200	100	145	85	1437
9	2500	25	145	85	3333
9	2500	20	145	85	3472
9	2500	10	145	85	3731
9	2500	10	145	85	4098
10	2250	100	145	85	1470
10	2375	25	145	85	3166
10	2375	20	145	85	3298
10	2375	10	145	85	3893
10	2375	10	145	85	3893
10	1750	55	145	85	1842
10	1430	40	145	85	1662
10	1430	33	145	85	1742

TABLE 5.2-1: HAST RESULTS (CONT'D)

Ref.	Time	% Fail	Temp.	RH	Estimated Characteristic Life (α)
10	1430	18	145	85	2042
10	1430	5	145	85	2750
10	1050	0	145	85	-
10	930	70	145	85	894
10	930	15	145	85	1388
10	930	5	145	85	1788
10	930	0	145	85	-
10	2000	16	145	85	2941
10	2000	18	145	85	2857
10	2000	5	145	85	3846
10	1000	100	145	85	653
10	1000	60	145	85	1020
10	1000	0	145	85	-
10	2600	48	145	85	2857
10	2600	45	145	85	2921
10	2600	28	145	85	3333

These characteristic lives were then analyzed with both Weibull and lognormal plots (Figure 5.2-3 and Figure 5.2-4, respectively). It can be seen that the lognormal distribution better fits the characteristic lives. It must be noted that this is not a distribution of times to failure of a homogeneous population, but rather it is a distribution of characteristic lives for a wide variety of PEM part types.

To quantify the TTF distribution of the entire population, a simulation was performed in which individual failure times were calculated based on the β of 4.5 and the estimated characteristic lives given in Table 5.2-1. Again, the lognormal distribution fit the data reasonably well. A summary of the analysis is given in Table 5.2-2.

TABLE 5.2-2: HAST DATA ANALYSIS SUMMARY

	Distribution	
Data Used	Weibull	Lognormal
Characteristic Life	$\alpha = 2238$ hrs. $\beta = 1.68$ $r^2 = .91$	$\mu = 1595$ $\sigma = 2.18$ $r^2 = .97$
Simulated TTF of Entire Population	$\alpha = 2269$ hrs. $\beta = 1.54$ $r^2 = .94$	$\mu = 1771$ hrs. $\sigma = 2.32$ $r^2 = .99$

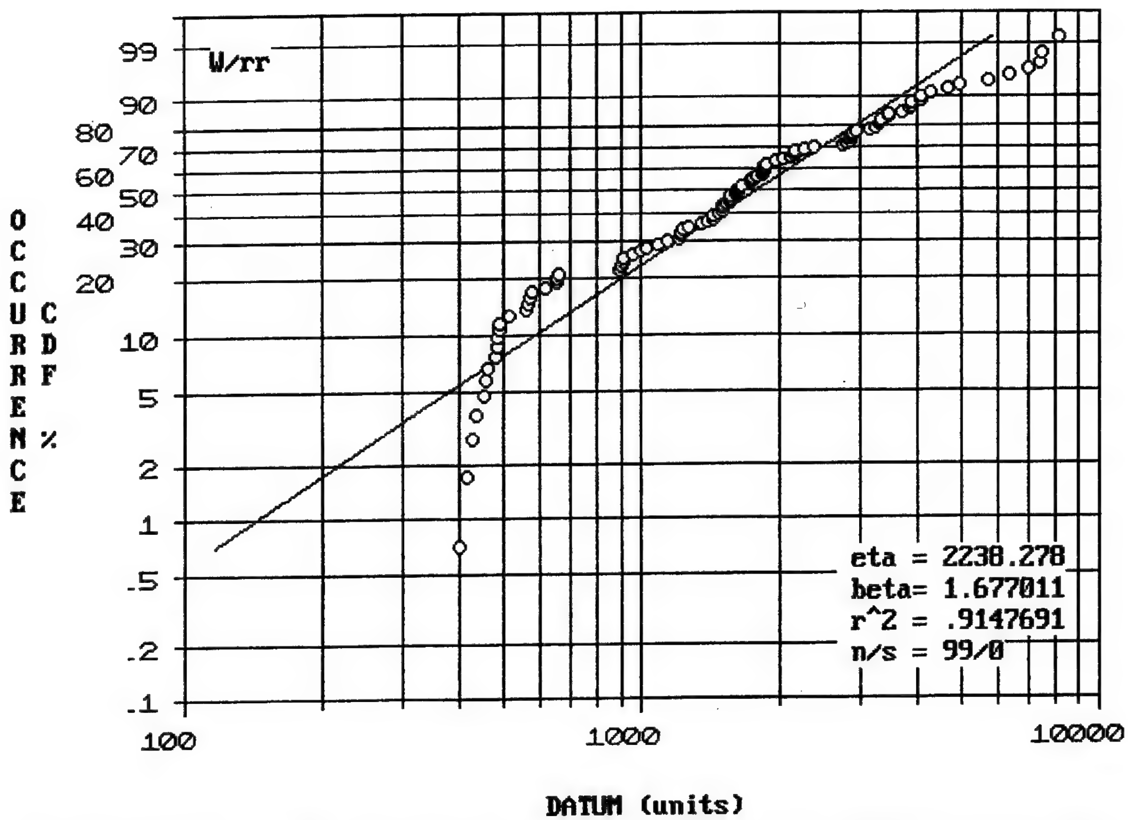

FIGURE 5.2-3: WEIBULL PLOT OF HAST CHARACTERISTIC LIVES

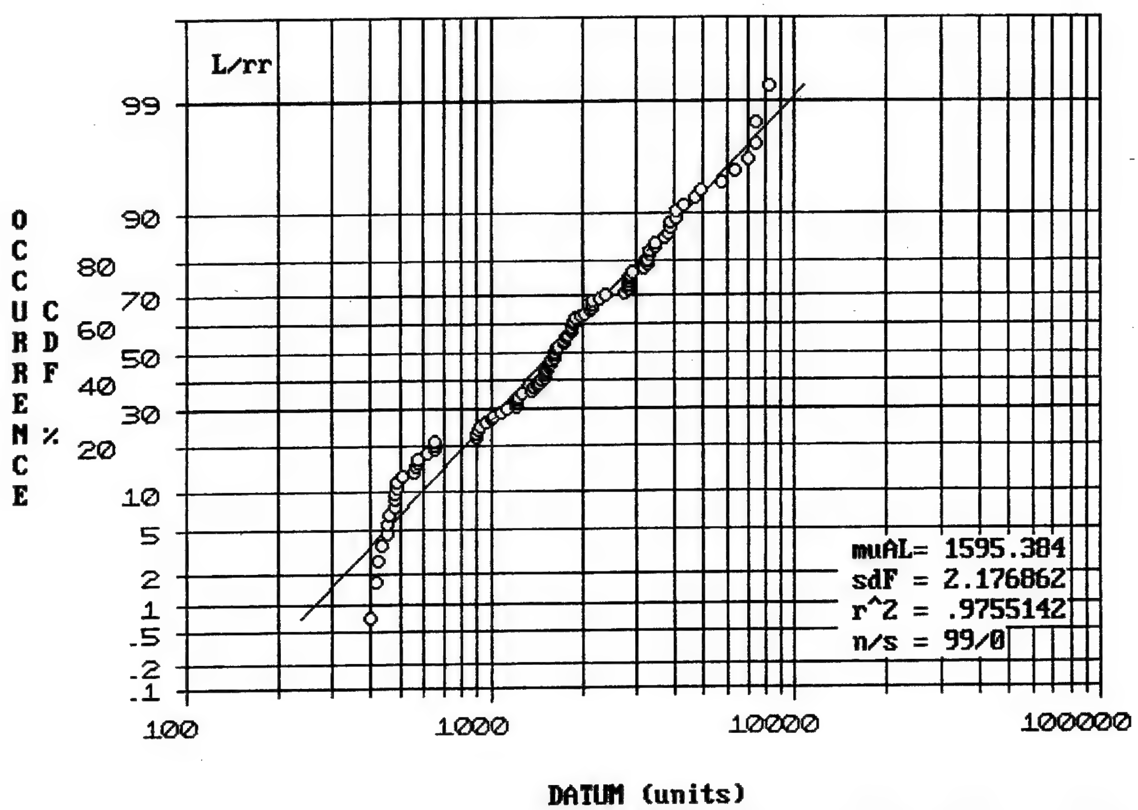

FIGURE 5.2-4: LOGNORMAL PLOT OF HAST CHARACTERISTIC LIVES

5.3 AUTOCLAVE Data

Table 5.3-1 presents a summary of the Autoclave data collected. The characteristic life (α) was estimated based on the maximum percent failed at the time given using an assumed β = 4.5. Figures 5.3-1 and 5.3-2 present these characteristic lives in a lognormal and Weibull plot, respectively.

TABLE 5.3-1: AUTOCLAVE DATA SUMMARY

Reference	Time	% Fail	Temp.	Pressure	α(est)*
12	452	40	-	-	525
12	452	2	-	-	1076
12	452	0	-	-	-
12	452	86	-	-	389
12	452	22	-	-	619
12	452	0	-	-	-
12	160	100	-	-	104
15	240	.00005	121°C	15 PSI	6000
15	240	0	121°C	15 PSI	-
15	240	3.6	121°C	15 PSI	580
15	240	3.08	121°C	15 PSI	521
15	240	1.9	121°C	15 PSI	571
15	240	2.5	121°C	15 PSI	545
19	48	.022	121°C	15 PSI	311
19	48	.024	121°C	15 PSI	305

(* assumes Weibull beta = 4.5)

5.4 Life Test

The Life Test data was analyzed using two different methodologies. The first summarizes the failure rates by calculating a failure rate based on the total observed number of failures and operating hours. The second was a Weibull analysis of the data that included times-to-failure for the observed failures. In both cases, the analysis was performed as a function of life test temperature, the year of part manufacture, and package specific failures causes vs. all failure causes.

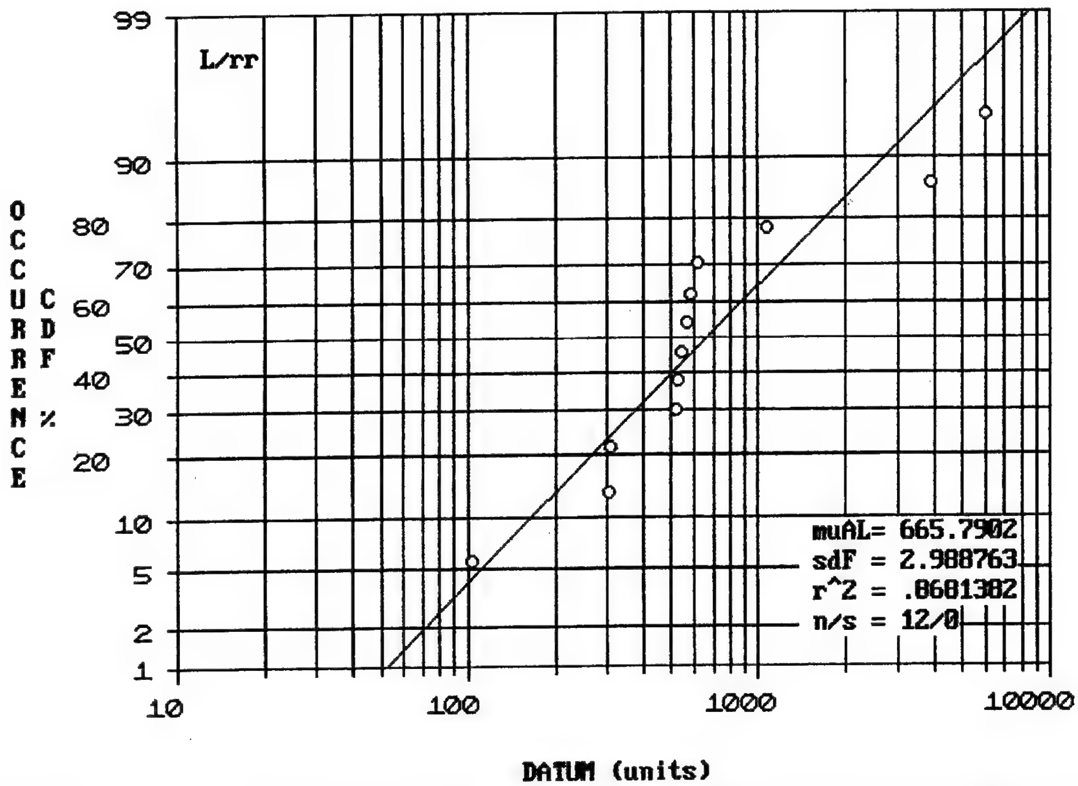

FIGURE 5.3-1: LOGNORMAL PLOT OF AUTOCLAVE CHARACTERISTIC LIVES

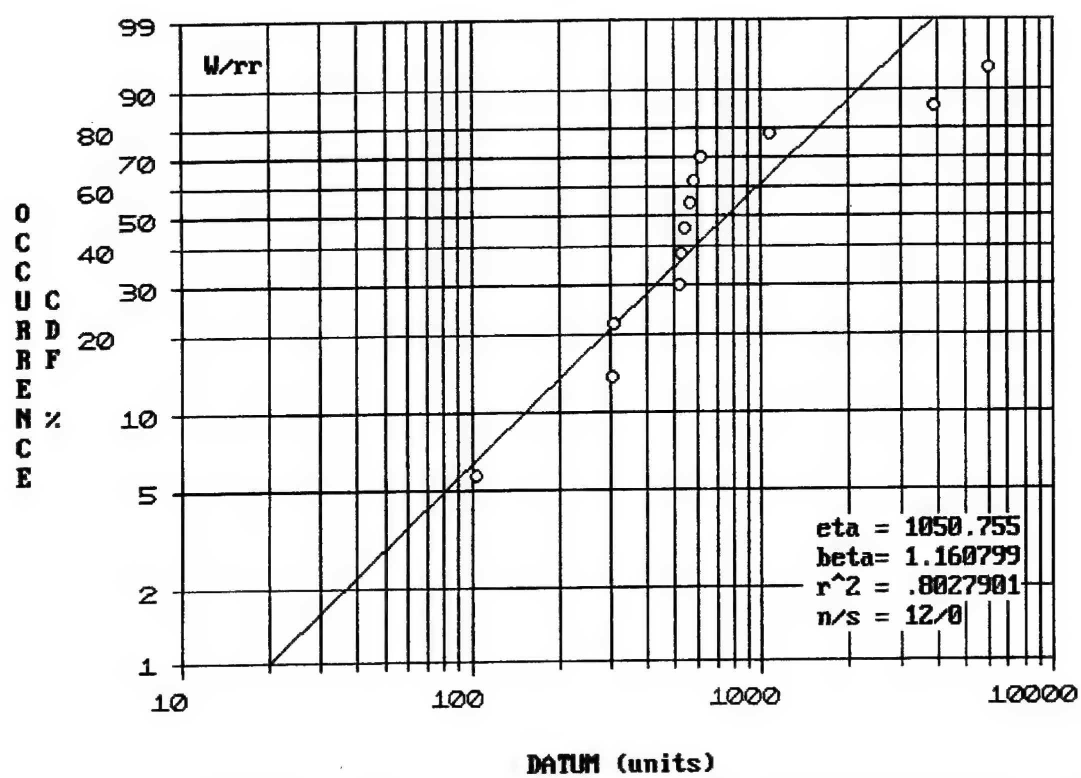

FIGURE 5.3-2: WEIBULL PLOT OF AUTOCLAVE CHARACTERISTIC LIVES

The Weibull analysis was accomplished by tabulating the characteristic life (α) and shape parameter (β) for all PEM devices of a given year and test temperature. It was necessary to group the data in this manner to gain enough data to make the analysis meaningful. As is the case with any situation in which a small percentage of the population fails, estimation of the time to failure distribution from the existing failures decreases the confidence in the resulting distribution. However, in this case, while the estimate of the characteristic life may be inaccurate, the value of the analysis is the estimation of the shape parameter. The shape parameter indicates whether the failures are predominantly infant mortality (beta less than one), random (beta close to one), or wearout (beta greater than one).

In all of the Weibull analyses, the best fit line was determined using the maximum likelihood estimation technique. RAC considers this method to be superior in cases where small percentages of the population have failed due to the fact that the higher cumulative percent failures are weighted more heavily.

Tables 5.4-1 through 5.4-5 summarize the life test data. Table 5.4-1 presents the data for both 125°C and 150°C tests for all failure causes. Table 5.4-2 presents the same data for only those failure causes classified as package related. Table 5.4-3 presents a summary of data from both temperatures for package failures and all failures.

TABLE 5.4-1: LIFE TEST RESULTS VS. YEAR AND TEMPERATURE FOR ALL FAILURE CAUSES

	125°C			150°C		
Year	Fail	Hours	λ	Fail	Hours	λ
80	26	20.8	1.25	12	2.27	5.28
81	26	8.70	2.98	4	2.40	1.67
82	28	4.86	5.76	6	2.20	2.73
83	50	10.2	4.90	7	5.21	1.34
84	84	14.1	5.95	16	8.45	1.89
85	53	11.3	4.69	8	3.81	2.10
86	21	7.40	2.83	-	-	-
87	-	-	-	0	.33	<3.0
88	-	-	-	28	17.32	1.62
89	-	-	-	21	25.3	.83
90	-	-	-	28	26.4	1.06
91	-	-	-	11	11.6	.95
92	-	-	-	0	4.64	<.21

TABLE 5.4-2: LIFE TEST RESULTS VS. YEAR AND TEMPERATURE FOR PACKAGE FAILURES

	125°C			150°C		
Year	Fail	Hours (10^6)	λ	Fail	Hours	λ
80	4	11.98	.33	5	2.27	2.20
81	8	10.55	.76	1	2.41	.41
82	6	4.85	.12	0	2.20	<.45
83	13	9.78	1.33	0	5.21	<.19
84	15	13.75	1.09	1	8.18	.12
85	16	11.22	1.43	0	3.81	<.26
86	0	7.08	<.14	-	-	-
87	-	-	-	-	-	-
88	-	-	-	0	16.9	<.060
89	-	-	-	2	24.1	.083
90	-	-	-	2	23.9	.084
91	-	-	-	0	9.53	<.10
92	-	-	-	0	4.33	<.23

TABLE 5.4-3: LIFE TEST RESULTS VS. YEAR AND FAILURE CAUSE

	Package Failures			All Failures		
Year	Fail	Hours	λ	Fail	Hours	λ
80	9	14.25	.63	38	23.1	1.6
81	9	12.96	.69	30	11.1	2.7
82	6	7.05	.85	34	7.06	4.8
83	13	14.99	.87	57	15.4	3.7
84	16	21.96	.73	100	22.5	4.4
85	16	15.13	1.06	61	15.11	4.0
86	0	7.08	<.14	21	7.4	2.8
87	0	0	-	0	.33	<3.0
88	0	16.9	<.06	28	17.3	1.62
89	2	24.1	.083	21	25.3	.83
90	2	23.9	.084	28	26.4	1.06
91	0	9.53	<.105	11	11.6	.95
92	0	4.33	.23	0	4.64	<.21

Includes data from 125°C and 150°C Life Tests

The Weibull analysis results are summarized in Tables 5.4-4 and 5.4-5 as a function of year and test temperature for all failure causes and for package failures. There appears to be no obvious trend in the data that would indicate either infant mortality or wearout failures are occurring. From this data, it appears as though a constant failure rate model is appropriate for life test conditions.

TABLE 5.4-4: SUMMARY OF WEIBULL ANALYSIS FOR ALL FAILURES

	125°C		150°C	
Year	α	β	α	β
80	356,000	1.14	34,738	1.47
81	2,811,000	.74	2,750,000	.81
82	2,5550,000	.66	1,116,000	.84
83	539,000	.84	1,115,000	.94
84	1,522,000	.72	15,126,000	.65
85	1,758,000	.70	1,016,000	.87
86	740,000	.89	3,671,000	.78
87	-	-	-	-
88	-	-	-	-
89	-	-	242,000	1.29
90	-	-	572,000	1.08
91	-	-	209,721	1.38
92	-	-	-	-

TABLE 5.4-5: SUMMARY OF WEIBULL ANALYSIS FOR PACKAGE FAILURES ONLY

	125°C		150°C	
Year	α	β	α	β
80	897,000	1.26	48,000	1.58
81	1,944,000	.727	-	-
82	1,836,000	.891	-	-
83	1,938,000	.875	-	-
84	493,000	1.10	-	-
85	6,801,000	.580	-	-
86	-	-	-	-
87	-	-	-	-
88	-	-	-	-
89	-	-	-	-
90	-	-	-	-
91	-	-	-	-
92	-	-	-	-

However, as will be shown in summarizing the failure mode/mechanism data, life tests accelerate predominantly die related failure mechanisms. Therefore, while life test times-to-failure appear to be exponentially distributed (constant failure rate), the time to failure characteristics for package related mechanisms may not be exponentially distributed due to their mechanical nature. While the TTFs for package failures during life test also appear to be exponentially distributed, it is probable that the life test stresses (temperature; electrical) are not accelerating defect related package failures.

5.5 85°C/85% RH

The 85°C/85%RH test data is summarized in Table 5.5-1. These characteristic lives are plotted in lognormal and Weibull plots in Figures 5.5-1 and 5.5-2, respectively. The characteristic life (α) was calculated by using the Weibull distribution with an assumed (β) value of 4.5. This shape parameter was chosen because it is characteristic of HAST data and because HAST and 85°C/85% RH tests accelerate the same type of failure mechanisms.

TABLE 5.5-1: 85/85 TEST DATA

Reference	Time	% Fail	α (est.)*
11	5,000	32	6,172
13	5,000	8	8,772
13	12,000	.8	25,294
13	4,000	2.3	9,302
15	1,000	.004	9,523
15	1,000	0	-
15	1,000	1.69	2,475
15	1,000	.47	3,289
15	1,000	.58	3,134
15	1,000	0	-
19	1,000	.044	5,586
20	3,000	0	-

*Assumes $\beta = 4.5$

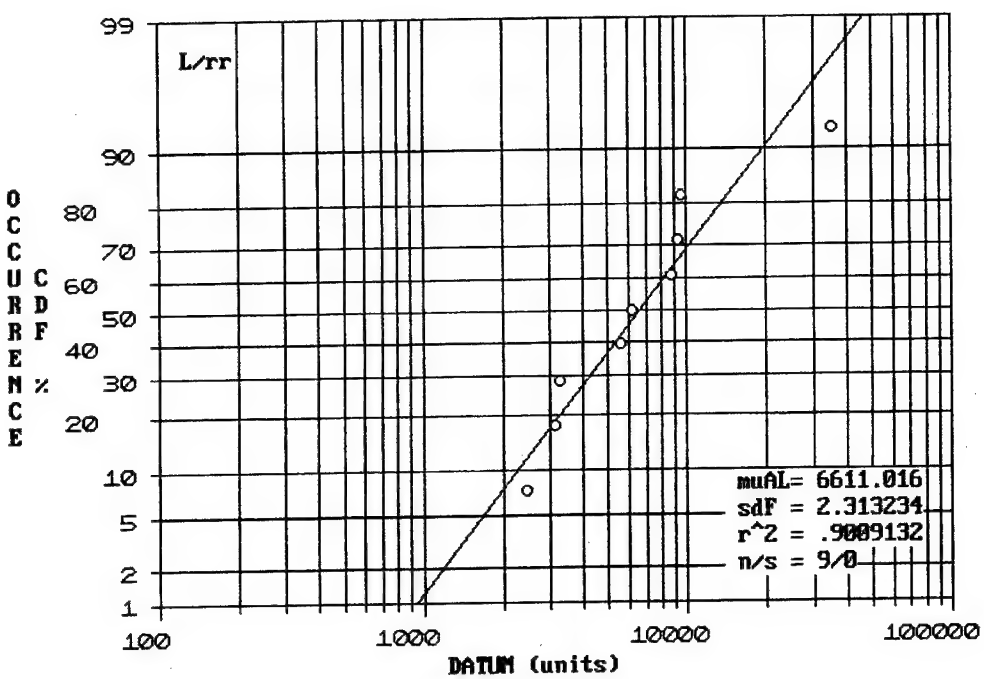

FIGURE 5.5-1: LOGNORMAL PLOT OF 85/85 CHARACTERISTIC LIFE ESTIMATES

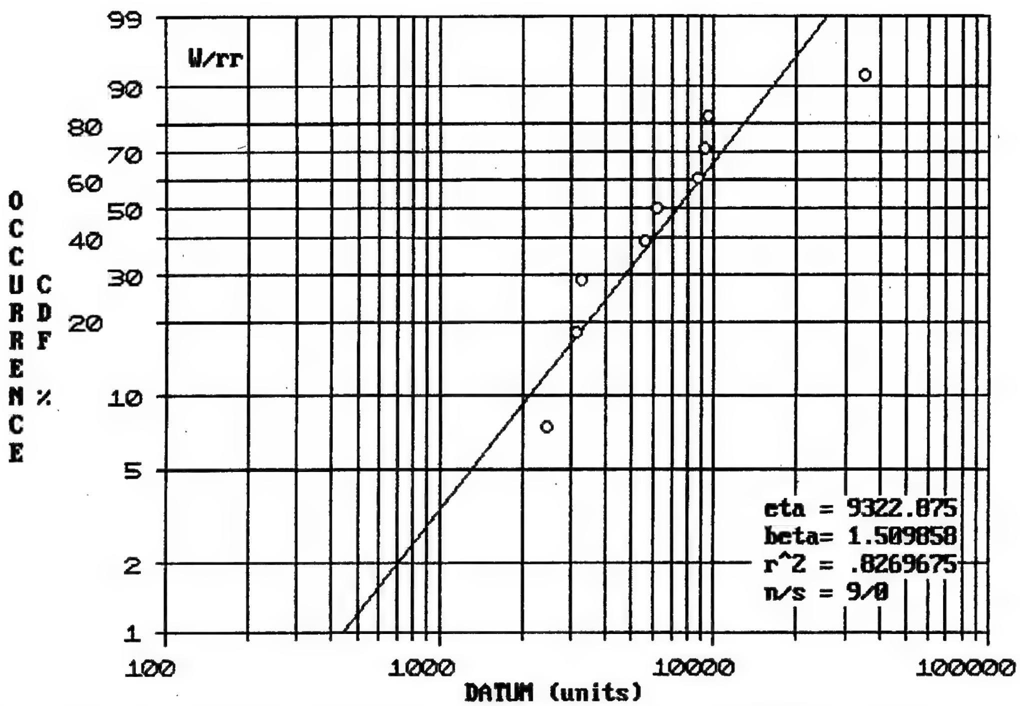

FIGURE 5.5-2: WEIBULL PLOT OF 85/85 CHARACTERISTIC LIFE ESTIMATES

5.6 High Temperature Storage Data

High Temperature Storage data is summarized in Table 5.6-1. Figures 5.6-1 and 5.6-2 contain a lognormal and Weibull plot of the characteristic life estimates, respectively. Figure 5.6-3 contains a histogram of β values determined from those datasets in which the data was adequate to perform a Weibull plot on the individual times-to-failure. The average β value calculated was 4.6.

TABLE 5.6-1: HIGH TEMP STORAGE DATA SUMMARY

Reference	Time	%	Temperature	α (est.) *
10	1650	60	200°C	1683
10	1650	0	200°C	-
10	1750	50	200°C	1902
10	1750	0	200°C	-
10	650	0	200°C	-
10	650	95	200°C	520
10	650	20	200°C	902
10	650	15	200°C	970
10	650	0	200°C	-
10	1100	0	200°C	-
10	1000	95	200°C	787
10	2100	100	200°C	1372

TABLE 5.6-1: HIGH TEMP STORAGE DATA SUMMARY(CONT'D)

Reference	Time	%	Temperature	α (est.) *
10	2100	0	200°C	-
9	425	100	200°C	277
9	700	100	200°C	457
9	700	100	200°C	457
9	700	100	200°C	457
9	850	100	200°C	555
9	2500	100	200°C	1634
9	2700	100	200°C	1764
9	2800	100	200°C	1830
9	1650	60	200°C	1683
9	1650	0	200°C	-
9	1900	50	200°C	2065
9	1900	0	200°C	-
9	1800	50	200°C	1956
9	1800	0	200°C	-
9	650	95	200°C	512
9	650	20	200°C	903
9	650	15	200°C	970
9	650	0	200°C	-

*Assumes $\beta = 4.5$

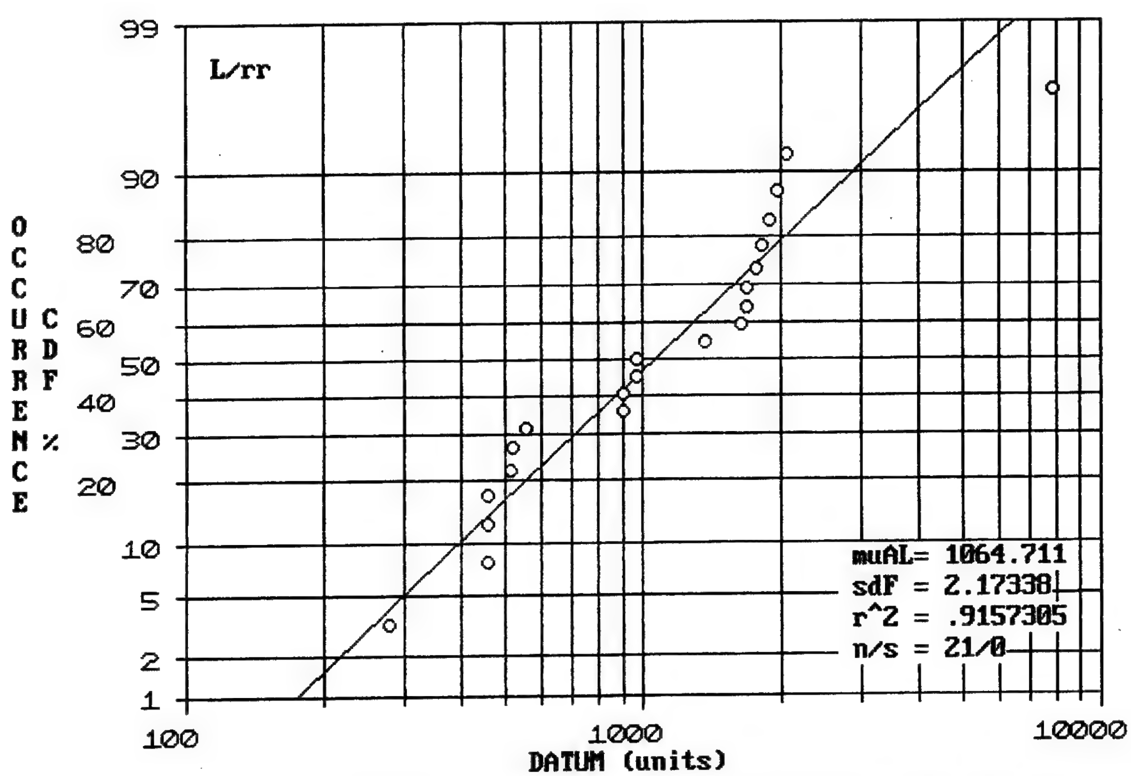

FIGURE 5.6-1: LOGNORMAL PLOT OF HIGH TEMPERATURE STORAGE CHARACTERISTIC LIFE ESTIMATES

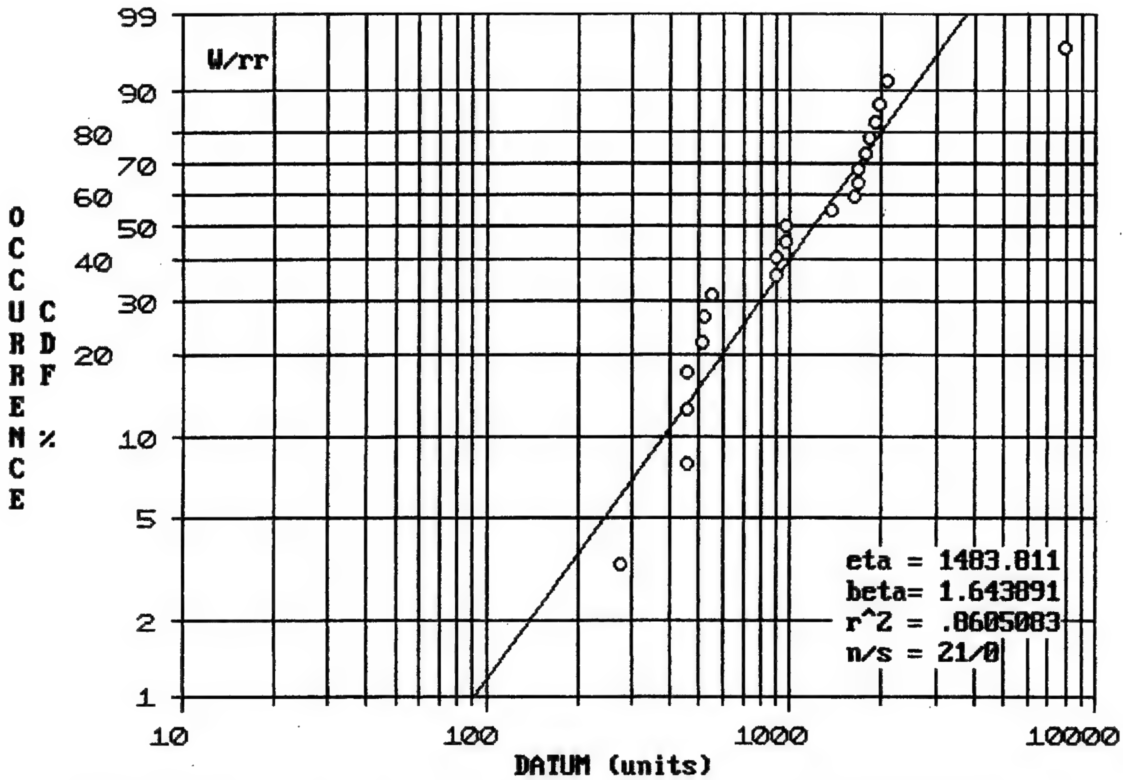

FIGURE 5.6-2: WEIBULL PLOT OF HIGH TEMPERATURE STORAGE CHARACTERISTIC LIFE ESTIMATES

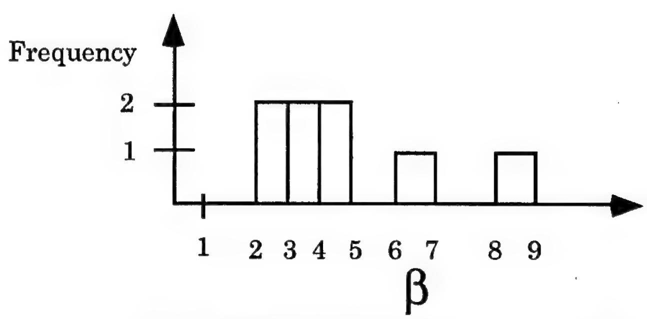

FIGURE 5.6-3: HIGH TEMP STORAGE β DISTRIBUTION (β AVERAGE = 4.6)

5.7 Temperature Cycling Data

Table 5.7-1 contains a summary of the temperature cycling data, including the characteristic life (in cycles) estimate. This characteristic life was calculated by assuming a Beta value of 3.5. This value was determined by performing a Weibull analysis on two of the data sets for which the cycles to failure data was adequate, yielding betas of 3.57 and 3.12.

Figures 5.7-1 and 5.7-2 contain lognormal and Weibull plots, respectively, of the characteristic life estimates.

TABLE 5.7-1: TEMP CYCLE DATA SUMMARY

Reference	# of Temperature Cycles	% Fail	ΔT T_{min} T_{max}	α (estimate in cycles)
11	1100	15.0	180 -55 125	1833
11	1100	11.0	215 -65 150	2075
15	1000	.03	215 -65 150	10,204
15	1000	1.0	215 -65 150	3704
15	1000	3.38	215 -65 150	2631
15	1000	4.06	215 -65 150	2500
15	1000	0.0	215 -65 150	-
15	1000	22.0	215 -65 150	1492
19	883	.03	125 -40 85	9010
19	1000	.25	215 -65 150	5555
19	1000	.083	215 -65 150	7692

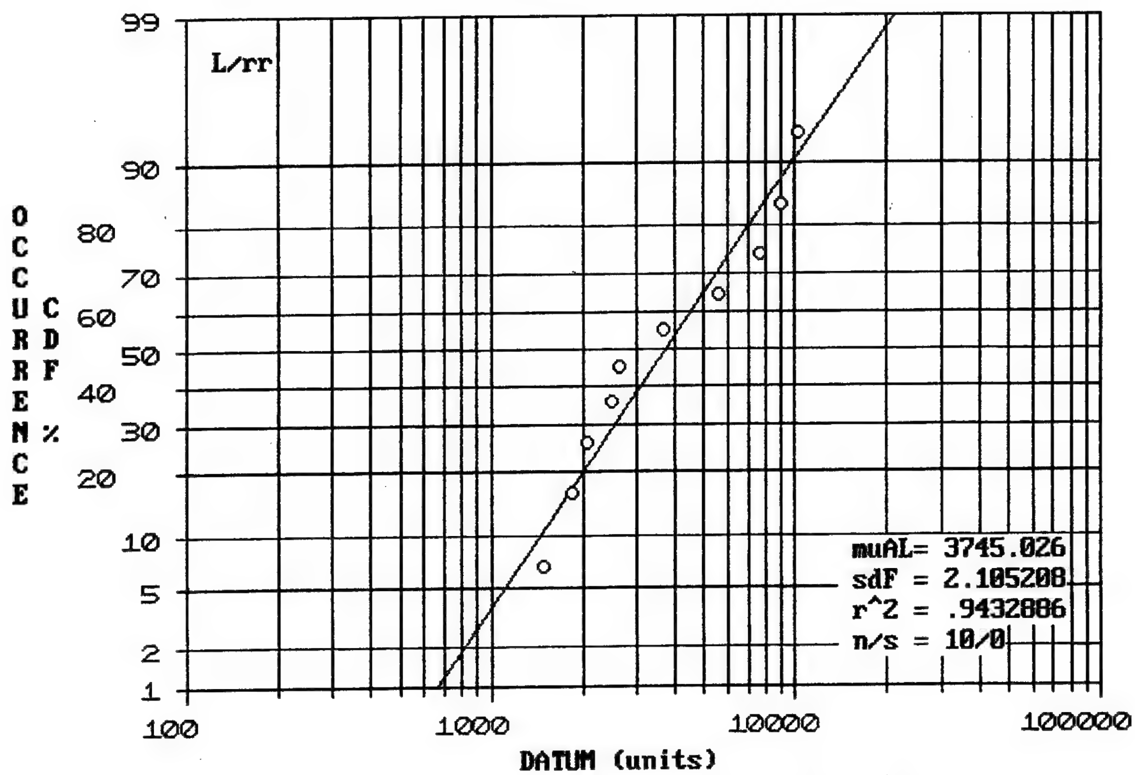

FIGURE 5.7-1: LOGNORMAL PLOT OF THE TEMPERATURE CYCLING CHARACTERISTIC LIFE ESTIMATES

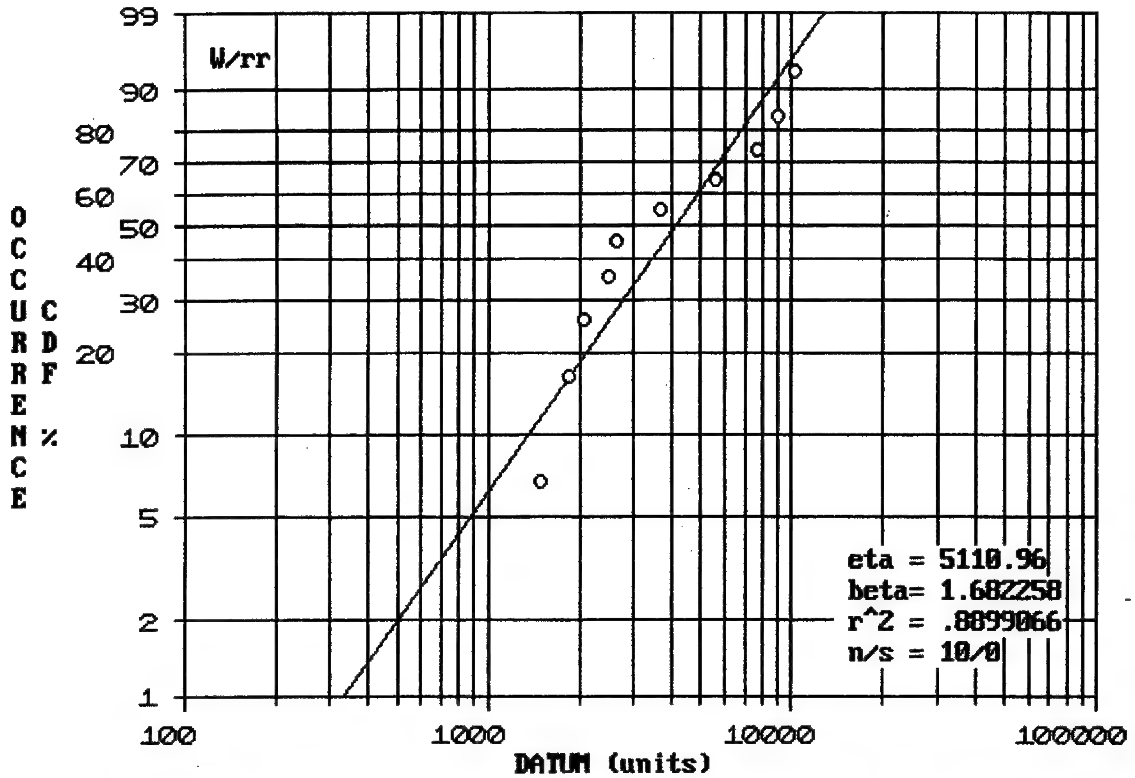

FIGURE 5.7-2: WEIBULL PLOT OF THE TEMPERATURE CYCLING CHARACTERISTIC LIFE ESTIMATES

5.8 Infant Mortality Statistics

An analysis was also performed to determine the degree to which infant mortality failures are prevalent. The only dataset that was able to quantify the failure rate as a function of time was the data taken from the automotive environment. This data was analyzed to determine the PEM time-to-failure characteristics. To accomplish this, the average failure rate between 0-3000 miles was compared to the average failure rate beyond 3000 miles. The ratio between these two failure rates, along with an equivalent Weibull shape parameter (β) is given in Table 5.8-1.

TABLE 5.8-1: INFANT MORTALITY CHARACTERISTICS

Device	$\frac{\lambda(< 3KMi)}{\lambda(> 3KMi)}$	Equivalent β
Digital, Bipolar	9.86	.19
Digital, MOS	6.35	.28
Linear	8.56	.22
Microprocessor, MOS	10.2	.19

Beta values less than one indicate that infant mortality is prevalent and that there is a decreasing failure rate in time as defective components are eliminated from the population. The data presented previously from life testing indicated beta values much closer to one (constant failure rate). There are several possible reasons for this discrepancy. First, it has been shown that life testing accelerates predominantly die related failure mechanisms and that field use accelerates predominantly package related mechanisms. It is possible that the defect rates that result in early life failures are not as high for die related mechanisms as they are for package related failure mechanisms. This is also consistent with the observation that die related failures represent a small percentage of all failures. A second possible explanation for this observance may be that the automotive environment is more stressful for the package related mechanisms, thereby causing the defective components to fail earlier, which in turn results in lower observed beta values. The reliability model presented in Section 6 uses the average failure rate for the first year of component operation.

5.9 Failure Modes/Mechanisms

Since an objective of this analysis is to quantify the reliability of PEMs, it is imperative to understand their failure modes under various conditions. To identify these failure modes and their relative probability of occurrence, data was collected which characterized the cause of failure. RAC data from high temperature accelerated life tests are summarized in Table 5.9-1.

TABLE 5.9-1: LIFE TEST FAILURE MODE DISTRIBUTION

Failure Mode	Number	Percentage	Normalized Percentage
Die	272	48	72
Package	105	18	28
Unknown	179	31	N/A
Induced	14	3	N/A

The normalized distribution excludes the unknown and induced categories. As can be seen from this distribution, life test conditions tend to accelerate die related failure mechanisms to a greater extent than package related mechanisms, which is expected since die related mechanisms tend to be more dependent on steady state temperature. The manner in which this distribution was derived was that each observed failure for which a cause was identified was classified into the above categories. Examples of these categories are given in Table 5.9-2.

TABLE 5.9-2: EXAMPLES OF PACKAGE AND DIE FAILURES

Package	**Die**
Wire	Oxide
Wire Bond	Metal
Contamination	Parametric Degradation
Foreign Contamination	Ionic Contamination
Die Attachment	Hot Carriers

Other references (Ref. 1, 19) have presented failure mode data on PEMs from both field and screening applications. Table 5.9-3, taken from Ref. 1, indicates the percentage of failed devices for each observed failure cause. The columns to the right of the percentage data are the RAC's classification of each into one of four categories. These categories, along with their associated failure sites or stresses, are listed in Table 5.9-4. The operational, environmental and ΔT categories are to be used in the reliability model to be presented in Section 6.

TABLE 5.9-3: PARETO RANKING OF FAILURE CAUSES IN FAILED PEMs**

Failure Causes	% of Failed Devices	Operational	Environmental	ΔT	Induced
Electrical overstress and electrostatic discharge	19.9				✓
Unresolved	15.9				
Gold ball-bond failure at bond	*9.0			✓	
Not verified	6.0				
Gold ball-bond fail at stitch bond	*4.6			✓	
Shear stress, chip surface	*3.5			✓	
Corrosion, chip metallization/assembly	*3.2		✓		
Dielectric fail, poly-metal, metal-metal	3.0	✓			
Oxide defect	2.9	✓			
Visible contamination	2.7		✓		
Metal short, metal open	*2.6	✓			
Latch-up	2.4	✓			
Misprocessed, wafer fab-related	2.4	✓			
Chip damage, cracks/scratches	*2.4				✓
Misprogrammed	2.0	✓			
Oxide instability	1.9	✓			
Design of chip	1.7	✓			
Diffusion defect	1.5	✓			
Final test escape	1.4				
Contact failure	1.2			✓	
Bond failure, non-gold	*1.2			✓	
Protective coating defect	0.9		✓		
Assembly, other	*0.9				
Polysilicon/silicide	0.8	✓			
External contamination	*0.7		✓		
Others	5.3				
		21.2%	7.5%	19.5%	

*= possible packaging/assembly related failures

NOTE: VLSI class devices were from multiple sources like manufacturing fallout, qualifications, reliability monitors, and customer returns.

**1. Ghate, R.b. Industrial perspective on Reliability of VLSI Devices, Texas Instruments (1992)
2. Pecht, M., Ramappan, V. "Are Components Still the Major Problem: A Review of Electronics System and Device Field Failure Returns", IEEE Trans. CHMT, Vol. 15, No. 6, December 1992.

TABLE 5.9-4: SUMMARY OF FAILURE CATEGORIES AND ASSOCIATED FAILURE SITES/STRESS

Failure Category	Predominant Failure Site/Stress
Operational	Die
Environmental	Temperature, Humidity
ΔT	Change in Temperature
Induced	Handling, EOS

Texas Instruments (Ref. 1) has also identified the failure causes from field returns. This data, along with the RAC's categorization, is summarized in Table 5.9-5. The total percentage was calculated by adding the percent failure attributed to each failure category over all failure modes.

TABLE 5.9-5: FIELD FAILURE MODES

			Failure Category		
Failure Mode	**%**	**Normalized %**	**Operational**	**Environ-mental**	**Temperature Cycling**
Bonding, Handling (Induced)	43	-	-	-	-
Cracked Package	16	29	-	-	29
Corrosion	13	23	-	23	-
Wire Sweep/Voids	10	17	-	-	17
Mold/Die Attach	5.5	9	-	-	9
Contamination	4.5	8	-	8	
Die Mechanical Damage	4.4	8	8	-	-
Adhesion	3.3	6	-	3	3
Total Percentage For Each Failure Category			8	34	58

Table 5.9-6 from Ref. 5 presents the distribution of failure causes under high humidity testing.

TABLE 5.9-6: FAILURE MODES UNDER HIGH HUMIDITY TESTING

			Failure Category		
Failure Mode	**%**	**Normalized %**	**Operational**	**Environ-mental**	**Temperature Cycling**
Corrosion	41	46	-	46	-
Contamination	24	27	-	27	-
Parameter Drift	12	14	14	-	-
Bond Related	11	12	-	-	12
Diffusion & Mask	1	1	1	-	-
Unknown	12	-	-	-	-
Total Percentage For Each Failure Category			15	73	12

Table 5.9-7 summarizes the failure distribution as a function of the data type and stress category. As expected, life tests predominantly accelerate operational failure modes (i.e., die-related), HAST testing accelerates predominantly environmental failure modes, and field applications accelerate a combination of both. It is interesting to note, however, that a relatively small percentage of failures, 8%, can be attributable to the die (operational) and that the majority, 92%, are package related, for both accelerated by environment and temperature cycling stresses.

TABLE 5.9-7: SUMMARY OF FAILURE CATEGORY DISTRIBUTIONS AS A FUNCTION OF DATA/TEST TYPE

Data Type	Operational	Environmental	Temperature Cycling
Life Test	72	28*	
Field/Test Combination	44	16	40
Field	8	34	58
HAST	15	73	12

* Life Test data of package failures was not categorized into its environmental and temperature cycling constituents.

5.10 Solder Joint Reliability

The data summarized thus far, and the models contained in Section 6 of this document, represent inherent component failures. In addition to the inherent component reliability, solder joints can also significantly influence the reliability of circuit assemblies. While the intent of this document is not to address solder joint reliability in detail, the available data is included to provide an estimate of their reliability. The automotive data source contained data adequate to quantify the solder joint reliability. The average failure rate for all ICs was .13 failures per million component operating hours. This failure rate is per component, not per solder joint. Additionally, this failure rate represents a mixture of surface mount technology and through-hole designs.

The infant mortality characteristics are similar to the inherent characteristics of the component itself with a failure rate ratio of 5.4 both before and after 3,000 miles. This yields an average beta value for the Weibull distribution of .32, indicating that the reliability of solder joints is a defect driven process.

5.11 Hermetic vs. PEM Reliability

The purpose of this document was not to study the reliability of hermetic parts or to make comparisons of hermetic and nonhermetic packages. However, several of the data sources contained data adequate to make a cursory comparison. Figure 5.11-1 contains the field failure rates of hermetic and nonhermetic devices from 1-year warranty data as a function of year for the ground benign data source. In this figure, only those years for which both hermetic and nonhermetic data was available are included.

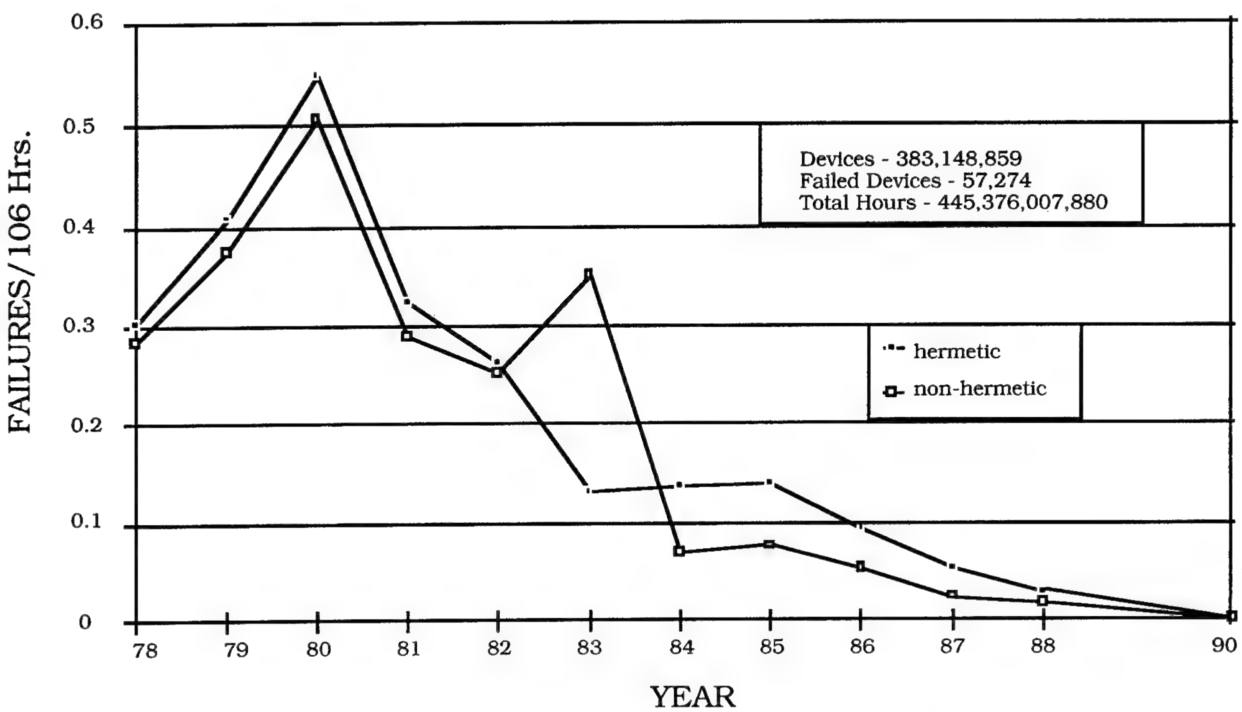

FIGURE 5.11-1: FAILURE RATES OF HERMETIC AND NONHERMETIC DEVICES

The commercial airborne data yielded an overall failure rate for ceramic devices of .033 failures per million hours vs. a failure rate of .045 for plastic devices.

Although both data sources indicate that there is not a significant difference in reliability, both sets of data were collected in the component's early life. As such, wearout failure mechanisms (i.e., corrosion) that may exist within PEMs may not have had time to manifest themselves and, therefore, comparison of their long term reliability cannot be made based on the available data.

6.0 RELIABILITY MODEL

The purpose of this effort was to collect as much data as possible so that conclusions could be made regarding the applicability of PEMs in various environments and operational states. The optimum way to determine this applicability is to quantify the reliability of all predominant failure mechanisms simultaneously under a specific set of operational stresses. To accomplish this, a reliability model has been developed based on the data collected.

Goals of this model are to:

- Accurately predict the field failure rate of PEMs under a wide variety of use conditions.
- Provide adequate sensitivity as a function of the predominant stress(es) reliability drivers.
- Predict the failure rates as a function of most operating scenarios.
- Include tailoring provisions that allow the use of empirical data on a specific product or product line (if available) to better predict field reliability.

The premise of the model is that failures are accelerated by the operational, environmental, and temperature cycling stresses discussed previously. Operational refers to electrical and temperature stresses incurred during operation. As such, the operational stresses act predominantly on the die. Environmental stresses refer to temperature and humidity to which the device is exposed continuously throughout its life. Temperature cycling refers to stresses incurred during a change in operating or ambient temperature.

Predominant PEM failure mechanisms are categorized into one of these three classes, depending on stresses that accelerate them. The failure rates for these three categories are then modeled individually and summed to yield the overall failure rate of the PEM. The form of the failure rate model is therefore:

$$\lambda_p = \lambda_{operational} + \lambda_{environmental} + \lambda_{temp.\ cycling}$$

where $\lambda_{operational}$ refers to the failure rate due to operational stresses, $\lambda_{environmental}$ refers to the failure rate due to environmental stresses, and $\lambda_{temperature\ cycling}$ refers to the failure rate resulting from changes in temperature.

The complete model form with all correction factors is:

$$\lambda_P = \Pi_{TYPE}\left[\lambda_{BO}\Pi_T\Pi_{DC}\Pi_{LT} + \lambda_{BE}\Pi_{RHT}\Pi_{HAST} + \lambda_{BTC}\Pi_{TC}\Pi_{CR}\Pi_{TCT}\right]\Pi_G$$

where,

λ_P = Predicted failure rate
Π_{TYPE} = Function of device type
λ_{BO} = Base operating die failure rate
Π_T = Temperature factor
Π_{DC} = Function of duty cycle
Π_{LT} = Tailoring factor as a function of life test data
λ_{BE} = Base environmental failure rate
Π_{RHT} = Acceleration factor as a function of temperature, relative humidity
Π_{HAST} = Tailoring factor as a function of HAST test data
λ_{BTC} = Base temperature cycling failure rate
Π_{TC} = Acceleration factor as a function of temperature extremes
Π_{CR} = Acceleration factor as a function of temperature cycling rate
Π_{TCT} = Tailoring factor as a function of temperature cycling test data
Π_G = Reliability growth factor as a function of year of manufacture

Features of the model include:

- Provisions that tailor the prediction if HAST, life test, or temperature cycling data is available.
- A factor which accounts for the growth in reliability that PEMs have experienced.
- Separate failure rates attributable to operational, environmental and temperature cycling stresses so that the user can see the stresses that are driving the failure rate.
- The use of industry accepted acceleration factors with constants derived from the empirical data.

- Provisions to estimate the average long term reliability by estimating the extrapolated (in time) failure rate due to known failure mechanisms.
- An output based on environmental and temperature cycling related failure rates, yielding a predicted failure rate in failures per million calendar hours which accounts for operating and nonoperating periods.

Since all failure mechanisms are accounted for, regardless of whether the part is operating or dormant, the failure rate unit for this model is in Failures per Million-Part-Calendar-Hours (F/10^6CH). This results in a flexible modeling methodology capable of predicting the reliability for virtually any operating scenario. This failure rate is essentially an average failure rate over the calendar time period in which the prediction is to be performed.

Given this form of the model, the cumulative failure rate (failure rate times time) must equal:

$$\lambda_{OBS} t_{OP} = \lambda_{OP} t_{TOT} + \lambda_{ENV} t_{TOT} + \lambda_{TC} t_{TOT}$$

where,

λ_{OBS}	=	Observed Failure Rate (Failures/10^6 CH)
t_{OP}	=	Operating Time (Hours)
λ_{OP}	=	Operational Failure Rate (Failures/10^6 CH)
t_{TOT}	=	Total Calendar Time (CH)
λ_{ENV}	=	Environmental Failure Rate (Failures/10^6CH)
λ_{TC}	=	Temperature Cycling Failure Rate (Failures/10^6CH)

The above equation is valid only for cases in which λ_{OBS} is determined by dividing the total number of failures by the total operating time, even though the failures may have resulted during nonoperating periods. This is the case with all field data collected in this study.

The cumulative observed failure rate must also equal the cumulative average failure rate:

$$\lambda_{OBS} t_{OP} = \lambda_{AVE} t_{TOT}$$

where,

λ_{AVE} = The average failure rate in failures/10^6 CH

$$\lambda_{AVE} = \lambda_{OBS}\frac{t_{OP}}{t_{TOT}} = \lambda_{OBS} \bullet DC \quad \left(\text{Duty Cycle (DC)} = \frac{t_{OP}}{t_{TOT}}\right)$$

The cumulative failure rate for each operating scenario is then set equal to the percentage of observed failures for each in the following manner:

$$(\lambda_{OBS}t_{OP})(.08) = \lambda_{OP}t_{TOT}(\text{Operating})$$
$$(\lambda_{OBS}t_{OP})(.34) = \lambda_{ENV}t_{TOT}(\text{Environmental})$$
$$(\lambda_{OBS}t_{OP})(.58) = \lambda_{TC}t_{TOT}(\text{Temp. Cycling})$$

where the constants .08, .34, and .58 are the average percentages of observed failures from field data due to each failure category.

If the predicted failure rate must be included in a reliability prediction using MIL-HDBK-217, the predicted failure rate in failures per million calendar hours must be converted to Failures per million operating hours. This can be converted by simply dividing the predicted failure rate (F/10^6 calendar hours) by the duty cycle (DC).

$$\lambda\left(F/10^6 \text{ op hours}\right) = \frac{\lambda\left(F/10^6 \text{ calendar hours}\right)}{DC}$$

6.1 Environmental/Use Conditions

In order to derive the PEM model, environmental and use conditions for the applications from which the data was collected must be estimated. While the exact conditions cannot be known, reasonable estimates can be made based on knowledge of similar applications in which measurements have been made. The best estimate of these values is given in Table 6.1-1.

TABLE 6.1-1: AVERAGE STRESS VALUES

	G_B	A_I	Automotive	Unit
Operational Ambient Temp(T_{AO})	30[1]	55[1]	58[2]	°C
Environmental Ambient Temp(T_{AE})	23[1]	14[1]	14[1]	°C
Relative Humidity (RH)	40	50	50	%
Average Change in Temp (ΔT)	7[1]	31[1]	44[2]	°C
Temp Cycle Rate (CR)	29,762[6]	228,161[7]	274,400[8]	cycles/10^6 hrs
Duty Cycle (DC)	30[3]	34[4]	4.6[5]	%

Notes:

1. Reference 30
2. Reference 31
3. 2600 hrs./yr. average operation = .30
4. 250 hrs./month operation average = .34
5. 400 hrs./yr. operation average = .046
6. (5 cycles/168 hrs.) (1,000,000) = 29,762 cycles/10^6 cal. hrs.
7. 1.5 hr./flight duration - 250 hrs./month
   (250 hrs./mo.)/(1.5 hrs./flight) = 167 flights/mo. x (1369 mo./10^6) = 228,167 cycles/10^6 hrs.
8. $200{,}300\ \frac{\text{cycles}}{10^6\ \text{mi.}}\left(\frac{1.37 \times 10^6\ \text{mi.}}{10^6\ \text{hrs.}}\right) = 274{,}400\ \frac{\text{cycles}}{10^6\ \text{hrs.}}$

6.2 Tailoring The Reliability Prediction

In the event that laboratory test data is available on a specific part, the model includes the provisions to tailor the prediction based on this data. Since the models are representative of devices with "average" lifetimes (when exposed to HAST, temp cycling or life tests), the resulting predictions yield average failure rates. By including the ability to tailor the models in accordance with empirical data on the specific part/manufacturer of interest, the accuracy and confidence in the prediction will increase.

The manner in which tailoring is accomplished is to multiply the failure rate for each of the three failure rate terms by a factor which is a function of empirical test data. Table 6.2-1 summarizes the failure rate term, the primary reliability driving parameters, and the data type that can be used to tailor the model.

TABLE 6.2-1: TEST DATA USED TO TAILOR MODEL

Failure Rate Term	Accelerating Factors	Test Type
Operational	Operating Temperature	High Temp Operating Life
Environmental	Relative Humidity, Temperature	HAST, 85/85
Temperature Cycling	Change in Temperature	Temperature Cycling

Derivation of each tailoring factor is presented in subsequent sections. Also, it is important to note that if the tailoring factors are to be used, there should be enough data to quantify the reliability in a statistically significant manner. For example, if HAST testing is performed for 100 hours on a population of PEMs with no failures, there is not sufficient information available to quantify its reliability. Ideally, in the case of HAST, testing would continue until a significant portion of the population had failed and a reasonable estimate of the mean life can be made. Even if the percent failure is small, however, a meaningful tailoring factor can be obtained if there is enough time accrued. In the case of HAST, the time at which this occurs may be 1500 - 2000 hours. In this case, there would be high confidence that the mean life of the PEMs being tested are higher than the average (1771 hours). For such a situation, a lower confidence limit of the mean life can be used.

The life test and temperature cycling tailoring factors should be based on enough data to estimate a failure rate (failures divided by cumulative hours or cycles). This will occur if there have been failures observed or, in the case of zero failures, when there have been a significant number of hours or cycles accrued.

6.3 Device Type Factor (Π_{TYPE})

The device type factor Π_{TYPE} was determined by taking the geometric mean of the observed failure rates between environments for various generic categories of device types. The observed failure rates are shown in Table 6.3-1 and the calculation of the Π_{TYPE} is given in Table 6.3-2.

TABLE 6.3-1: SUMMARY OF OPERATING FAILURE RATES

	A_I	G_M	G_B
Linear	.054	.32	.003
Digital SSI/MSI	.010	.11	.00097
Microprocessor/Memory	.14	.13	.0023

Normalizing to digital device types and calculating the ratios between types yields the Table 6.3-2 Π_{TYPE} factors.

TABLE 6.3-2: CALCULATION OF Π_{TYPE}

	A_I	G_M	G_B	Π_{TYPE} (Geometric Mean)
Digital	1.0	1.0	1.0	1.0
Linear	5.4	2.91	3.09	3.65
Microprocessor/Memory	14.0	1.18	2.37	3.40

An analysis was also undertaken to determine if there were significant differences in the package type (i.e., leaded vs. surface mount). From the data that was collected, there appeared to be no significant differences that could be discerned. This indicates that either the data was not good enough to identify such differences or that other factors influence reliability to a much larger degree than does package type. Although the data collected in this study could not distinguish the difference in reliability between either package type or preconditioning, recent test data has indicated that both can influence the lifetime of the PEM. Indications are that preconditioning lowers the lifetime and that DIPs have longer lifetimes than surface mount packages. However, if empirical test data is used to tailor the models, then the prediction will be customized to the specific component and package type of interest.

6.4 Operational Failure Rate

6.4.1 Temperature Acceleration Factor

Derivation of the temperative acceleration factor (Π_T) is based on the premise that temperature is the primary stress that differentiates the conditions of field usage in ground benign environments and high temperature operating life tests. The form of the temperature acceleration factor (Π_T) is the Arrhenius relationship, given as follows:

$$\Pi_T = \exp\left[\frac{-Ea}{K}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

where,

Ea is the activation energy (ev) to be derived from the empirical data

K is Boltzman's Constant (6.317×10^{-5}) (ev/°K)

T_1, T_2 are the junction temperatures (in °K) between which the acceleration factor is to be calculated.

The data in Table 6.4-1 was used to determine the activation energy (E_a).

TABLE 6.4-1: DATA USED TO DERIVE ACTIVATION ENERGY

Environment/ Data Type	Average Ambient Temperature	Failure Rate	
		Die	Package
Life Test	137°C	.509	.0989
Ground Benign/Field	30°C	.0021	

A premise of this model is that die related failure modes are primarily accelerated by temperature whereas package related failures are accelerated by the temperature/humidity combination and temperature cycling. Therefore, it was desired to derive a Π_T only for the die portion of the failure rate. Since detailed knowledge of the precise failure modes comprising the above distribution representing the field data is unknown, there is uncertainty regarding the field failure rate for die related failure modes. If all failure modes are accounted for, the derived equivalent activation energy using the above relationship for Π_T is .56 ev. This is also the activation energy that would be derived if it is assumed that the die/package failure rate ratio is the same for both field and life test data. If it is assumed that 8% of field failures are due to die related mechanisms (with a resulting failure rate of .08 x .0021 = .000168), the derived activation was calculated as follows:

$$\frac{.509}{.000168} = \exp\left[\frac{-Ea}{K}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

where,

$T_1 = 273 + 137 = 410°K$
$T_2 = 273 + 30 = 303°K$
Solving for Ea yields an activation energy of .80

Although there is uncertainty regarding the die field failure rate, the values of .56 and .80 establish a valid range. Since all evidence suggests that the percentage of failures attributable to the die decreases from life test to field conditions, the upper end of the range is more likely to be accurate. Therefore, normalizing to 25°C yields the final Π_T acceleration factor:

$$\Pi_T = \exp\left[\frac{-.80}{K}\left(\frac{1}{T_J} - \frac{1}{298}\right)\right]$$

The temperature factor (Π_T) is a function of the application environment and device type. The ambient temperature varies as a function of environment and the junction temperature rise varies as a function of device type. Therefore, to derive the remaining portions of the operating failure rate (λ_{BO}), the temperature factor, Π_T, is needed for the nine combinations of environment and device type that comprise the field data. Typical values of temperature rise due to power dissipation were used to determine the average junction temperature. Table 6.4-2 presents the values that were assumed, along with the associated temperature rise.

TABLE 6.4-2: ASSUMED PARAMETERS USED TO CALCULATE TEMPERATURE RISE

Component Type	θ_{JC}(°C/W)	Power (Watts)	TRISE (°C)
Linear	50	.5	25
Digital SSI/MSI	45	.3	13
Microprocessor	40	.5	20

As previously stated, the die portion of the failure rate model is:

$$\lambda_{operational} = \lambda_{BO}\Pi_{TYPE}\Pi_T\Pi_{DC}\Pi_{LT}$$

The average observed die failure rate is then equated to the right side of the equation and solved for λ_{BO}.

$$\lambda_{BO} = \frac{\lambda_{OP(observed)}}{\Pi_{TYPE}\Pi_T\Pi_{DC}\Pi_{LT}}$$

Table 6.4-3 summarizes the data used to derive λ_{BO}. Included in the table is the device type (Type), environment (Env.), average ambient temperature (T_{AO}), temperature rise from typical power dissipation levels (T_{rise}), the associated temperature acceleration factor (Π_T), the device type multiplication factor (Π_{TYPE}), the average observed failure rate (λ_{OBS}), failure rate associated with operation ($\lambda_{operational}$) (assumed to be 8% of the total failure rate), and the base operating failure rate (λ_{BO}) calculated from the above equation. Both Π_{DC} and Π_{LT} are set equal to one for this analysis since they will be normalized to one for the average conditions of the data.

TABLE 6.4-3: DATA USED FOR DERIVATION OF OPERATIONAL* BASE FAILURE RATE

Type	Env.	T_{AO}	T_{rise}	Π_T	Π_{TYPE}	λ_{OBS}	λopera-tional*	λ_{BO}
Linear	A_I	55	25	128	3.65	0.054	.0015	3.14×10^{-6}
Digital	A_I	55	13	50.8	1	0.01	.0003	5.35×10^{-6}
Microp/mem	A_I	55	20	87.9	3.4	0.14	.0038	1.27×10^{-5}
Linear	G_B	30	25	17.3	3.65	0.993	$7x10^{-5}$	1.41×10^{-6}
Digital	G_B	30	13	5.9	1	0.00097	$2x10^{-5}$	3.95×10^{-6}
Microp/mem	G_B	30	20	11.1	3.4	0.0023	$6x10^{-5}$	1.45×10^{-6}
Linear	G_M	58	25	160	3.65	0.32	.0012	2.02×10^{-6}
Digital	G_M	58	13	64.4	1	0.11	.0004	6.28×10^{-6}
Microp/mem	G_M	58	20	110	3.4	0.13	.0005	1.27×10^{-6}
								3.05×10^{-6}

$* \lambda_{operational} = \lambda_{observed} \cdot (.08) \cdot DC$

To convert the operating failure rate to a failure rate in failures per million calendar hours, the operating failure rate is multiplied by the duty cycle. To accomplish this, the duty cycle factor is:

$$\Pi_{DC} = \frac{DC}{.17}$$

Where DC = duty cycle (percent of calendar time in which the device is operating) and .17 is the average duty cycle representing the applications from which the data was collected.

The geometric mean of the $\lambda_{BO's}$ was then calculated. This value is 3.05 x 10^{-6}F/10^6 calendar hours. Therefore, the die portion of the failure rate model is:

$$\lambda_{op} = 3.05 \times 10^{-6}\ \Pi_{TYPE}\ \Pi_T\ \Pi_{LT}$$

where,

Π_{TYPE} = 1.0 for Digital SSI/MSI
3.65 for Linear
3.40 for microprocessors/memories

Π_{LT} = function of life test results for specific device on which prediction is being performed (Section 6.4.2).

$$\Pi_T = \exp\left[-\frac{.8}{K}\left(\frac{1}{T_J} - \frac{1}{298}\right)\right]$$

where,

$$K = 8.617 \times 10^{-5}\left(\frac{Ev}{°K}\right)$$

6.4.2 Tailoring the Operational Failure Rate Factor

The operational failure rate multiplying factor is simply the observed failure rate from life tests (converted to an equivalent life test failure rate at 137°C ambient temperature) divided by the average observed life test failure rate. The observed average life test failure rate for 1992 is .608 F/10^6 hrs. at an average temperature of 137°C ambient and an average temperature rise of 18.7°C. The multiplying factor then becomes:

$$\Pi_{LT} = \frac{\lambda_{(life)}}{.608}\frac{\Pi_T(137,\ 18.7)}{\Pi_T(\text{Life Test})}$$

where,

λ_{life} = the observed failure rate from life test results (F/10^6hrs.)

$$= \frac{\text{Total Number of Failures}}{\text{Cumulative Number of Part Hrs. (in million hours)}}$$

Π_T (137, 18.7) is the temperature acceleration factor for the average life test conditions and is calculated as follows:

$$\pi_T = \exp\left[-\frac{.8}{K}\left(\frac{1}{137 + 18.7 + 273} - \frac{1}{298}\right)\right] = 13{,}335$$

Π_T (life test) is the temperature acceleration factor corresponding to the specific life test ambient temperature and temperature rise

Therefore the life test tailoring factor is:

$$\Pi_{LT} = \frac{\lambda_{(life)}}{.608}\left(\frac{13335}{\Pi_{T(life)}}\right)$$

6.5 Environmental Failure Rate

The failure rate due to ambient temperature and humidity was then modeled. Due to its acceptance within the industry, Pecks model form (Ref. 30) is used. This form indicates that the mean life of a PEM is proportional to:

$$(RH)^{-n}\exp\left(\frac{Ea}{KT}\right)$$

where,

Ea	=	Activation energy for moisture related failure modes (Ev)
K	=	Boltzmans Constant (Ev/°K)
T	=	Temperature (°K)
RH_{eff}	=	Effective Relative Humidity (Percent)
n	=	Constant

For the purpose of this model, the failure rate can be assumed to be proportional to the reciprocal of the life. This has been shown to be a good approximation for small cumulative percent failure. The failure rate is then:

$$\lambda = \lambda_{BE} \exp\left[-\frac{Ea}{KT}\right](RH)^n = \lambda_{BE}\Pi_{RHT}$$

where,

λ_{BE} is a base environmental failure rate constant fit to the observed data.

$$\Pi_{RHT} = \exp\left[\frac{-Ea}{KT}\right](RH)^n$$

The value of the activation energy (E_a) reported in the literature ranges from .79 to .90. The data collected during this study was analyzed to determine the equivalent activation energy that accounts for the acceleration between 85°C/85% RH and HAST testing. The mean lifetimes observed for 85/85 and HAST testing were 6611 and 1595 hours, respectively, which corresponds to an activation energy of .34 ev.

The value of n has reportedly varied from 2.66 to 4.64 with a commonly accepted value of 3.0 (Ref. 30), which is the value to be used in the model.

If the duty cycle is not 1.00, the average effective RH_{EFF} must be used to calculate the expected mean life (Ref. 31). Calculating this average value as a function of the junction and ambient RH's yields:

$$RH_{EFF} = DC\, RH_{EFF\,(op)} + (1 - DC)\, RH_{EFF\,(dor)}$$

where,

DC	=	duty cycle (% operating time)
RH_{EFF}	=	effective relative humidity
RH_{EFF} (op)	=	operating effective RH
RH_{EFF} (dor)	=	dormant effective RH
RH	=	relative humidity of the environment

$$RH_{EFF} = DC(RH)\exp\left[5230\left(\frac{1}{T_{J1}} - \frac{1}{T_{AO}}\right)\right] + (1-DC)(RH)\exp\left(\frac{1}{T_{J2}} - \frac{1}{T_A}\right)$$

TAO = normalizing temperature
TJ1 = operating junction temperature
TJ2 = nonoperating junction temperature ($T_{J2} = T_A$)

$$RH_{EFF} = (DC)\,(RH)\exp\left[5230\left(\frac{1}{T_J} - \frac{1}{T_{AO}}\right)\right] + (1-DC)\,(RH)$$

where,

$$T_J = T_{AO} + \theta_{JA}P$$

The RH_{EFF} was then calculated for each data point using the values in Table 6.1-1. Normalizing the temperature factor to 25°C, the RH_{EFF} to .50 and calculating the geometric mean of the λ_{BE} values that are necessary to equate the predicted and observed failure rates yields a λ_{BE} value of .00046 F/10^6 calendar hrs.

Since the Π_{RHT} factor is the acceleration factor for the MTTF, it must be converted to an acceleration factor for the failure rate. It was attempted to make this conversion by calculating the ratio of expected cumulative lognormal percent failure under use conditions to the lognormal percent failure under average conditions (to which the models are normalized). However, modeling the Pi factor in this manner resulted in a factor that was much too sensitive to the time over which the failure rate was calculated. The actual data did not vary nearly as much as the Pi factor would indicate. The acceleration factor (Π_{RHT}) as a direct multiplier was a much more accurate indicator of the failure rate acceleration as a function of temperature and humidity. The probable explanations for this observance are that (1) the lognormal distribution's accuracy at its extreme left side is limited and (2) the failures observed in the field data are not common cause (which lognormal statistics model), but rather are special cause which are usually better modeled with a constant failure rate. Therefore, since it fits the observed data to a much higher degree, the acceleration factor will be used as the Pi factor.

The environmental failure rate portion of the model is, therefore:

$$\lambda_{ENV} = \lambda_{BE}\Pi_{TYPE}\Pi_{RHT}\Pi_{HAST}$$

where,

λ_{BE} = .00046

$$\Pi_{RHT} = \exp\left[\frac{-.34}{.00008617}\left(\frac{1}{T_{AE}} - \frac{1}{298}\right)\right]\left[\frac{RH_{EFF}}{.5}\right]^{-3}$$

T_{AE} = Environmental ambient temperature

6.5.1 Environmental Failure Rate Tailoring Factor

The environmental tailoring factor (Π_{HAST}) is a function of the mean time to failure under HAST testing, the HAST test conditions, the temperature and relative humidity of the use application environment, and the time period over which the average failure rate is desired. This factor is calculated by converting the MTTF under HAST testing to an estimated MTTF under use conditions, determining the cumulative failure percentage for the time period of interest, and then dividing by the cumulative percentage failure predicted under the average conditions and time intervals of the data collected. This results in the ratio of expected cumulative percent failure under use conditions to the cumulative percent failure from the data that was collected. By customizing the predictions in this manner, empirical HAST (or 85/85) data can be utilized to determine if component wearout mechanisms (moisture related corrosion) will result in unacceptably high failure rates over the time periods of interest.

The Peck model (Ref. 30) described previously is the acceleration factor for mean time to failure, which is lognormally distributed. Since the model developed herein predicts the failure rate, the acceleration factor must be converted from a MTTF accelerator to a failure rate accelerator. This was accomplished by assuming that the percent failure of the population is proportional to its failure rate. While this is not correct for repairable systems, it represents a very good approximation when small cumulative percent failures

are experienced. Since this model intends to predict the failure rate during a part's useful life, the model is only valid for small cumulative percent failure. Therefore, the model factor will have no more than 20% error if the cumulative percent failure is less than 20. This is the valid range of the model, and values beyond this range are left blank in the table which summarizes the Π_{HAST} factor.

The Π_{HAST} factor is, therefore:

$$\Pi_{HAST} = \frac{\%\text{ Fail (use conditions)}}{\%\text{ Fail (average conditions of data)}}$$

Percent failure (use conditions) is the cumulative percent failure per year for the lognormal distribution, over the time period of interest and under use conditions extrapolated from HAST data. Percent failure (average use conditions) represents the cumulative percent fail at 8760 hours, which is the calendar time over which the data was collected under its average use conditions.

By structuring the factor in this manner, the models can be used to calculate average failure rates under use conditions beyond one year simply by calculating the % Failure under use conditions at the time of interest. This time will usually be the design life of the equipment in which the PEM is to operate.

The Π_{HAST} factor was derived by the following specific steps:

1) The mean lifetime was calculated for the average conditions of the field data used to derive the model by extrapolating from the HAST test results. The average conditions of this data were 48°C and 40% Relative Humidity, yielding a Π_{RHT} of 1.29. The acceleration factor for the average HAST test results (137°C, 85RH) on which the model factors are normalized is 182.9. The mean life for these HAST conditions was 1771 hours. Therefore the expected mean life under the average field use conditions is:

$$(1771\text{ hours})\frac{182.9}{1.29} = 251{,}000\text{ hours}$$

2) A realistic range around this mean lifetime was determined. From the HAST distribution and the difference in acceleration factors between least/most severe environments, it was determined that approximately 80% of all situations would fall into the range .12 to 7.5 times the mean

life. Therefore .1 to 10 times the mean life was used, which translates to a range of 25,100 to 2,510,000 hours.

3) For incremental mean life values within this range, the cumulative percent failure was calculated for times from one to twenty years using the lognormal TTF distribution. These times represent the period over which the average failure rate is to be determined. It may represent the design life of the equipment in which the PEM is to operate. The standard deviation used was 2.25 which was obtained from the HAST test data analysis presented in Section 5. These values were divided by the total number of years in each time interval, yielding the average percent fail per year.

4) This value was then divided by the percent failure during average conditions of the data collected, which was 48°C, 40% RH, and a time period of one year. This value is .0000335 or .00335%. By dividing by this value, the factor is normalized to average conditions of the data on which the models are based.

These values were calculated by:

$$\Pi_{HAST} = \frac{CDF_{log\,normal}\,(t_1, \mu_1, sd)}{(\text{Years})\ CDF_{lognormal}(t_2, \mu_2, sd)}$$

where,

$CDF_{lognormal}\ (t_1, \mu_1, sd)$ is the cumulative percent failure at t_1 hours (years x 8760), an equivalent mean life at 48°C, 40% RH of μ, and a standard deviation (sd) of 2.25.

(Years) is the number of years over which the average failure rate is desired.

$CDF_{lognormal}\ (t_2, \mu_2, sd)$ is the cumulative percent failure at t_2 (8760 hours), μ_2 (251,000), and a standard deviation (sd) of 2.25.

Table 6.5-1 illustrates the failure rate multiplying factors for the environmental failure rate portion of the model as a function of mean life and time. Note that the temperature and RH of the use environment is not accounted for in the Π_{HAST} factor, since it has already been accounted for in the Π_{RHT} factor.

TABLE 6.5-1: Π_{HAST} VS. HAST MEAN LIFE AND TIME

	Years																			
μ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
25100	3.1E+3																			
27108	2.7E+3																			
29276.64	2.3E+3																			
31618.771	1.9E+3																			
34148.273	1.6E+3	3.2E+3																		
36880.135	1.3E+3	2.8E+3																		
39830.546	1.1E+3	2.5E+3																		
43016.989	8.7E+2	2.1E+3																		
46458.348	7.1E+2	1.8E+3																		
50175.016	5.7E+2	1.6E+3																		
54189.017	4.5E+2	1.3E+3	1.9E+3																	
58524.139	3.6E+2	1.1E+3	1.7E+3																	
63206.07	2.8E+2	9.5E+2	1.5E+3																	
68262.556	2.2E+2	7.9E+2	1.3E+3	1.6E+3																
73723.56	1.7E+2	6.5E+2	1.1E+3	1.4E+3																
79621.445	1.3E+2	5.4E+2	9.3E+2	1.2E+3																
85991.16	9.9E+1	4.4E+2	7.9E+2	1.1E+3	1.3E+3															
92870.453	7.5E+1	3.5E+2	6.6E+2	9.2E+2	1.1E+3															
100300.09	5.6E+1	2.8E+2	5.5E+2	7.9E+2	9.7E+2	1.1E+3														
108324.1	4.2E+1	2.3E+2	4.6E+2	6.7E+2	8.4E+2	9.7E+2														
116990.02	3.1E+1	1.8E+2	3.8E+2	5.7E+2	7.2E+2	8.5E+2	9.4E+2													
126349.23	2.3E+1	1.4E+2	3.1E+2	4.8E+2	6.2E+2	7.4E+2	8.3E+2													
136457.16	1.6E+1	1.1E+2	2.5E+2	4.0E+2	5.3E+2	6.4E+2	7.3E+2	8.0E+2												
147373.74	1.2E+1	8.5E+1	2.0E+2	3.3E+2	4.4E+2	5.5E+2	6.3E+2	7.0E+2												
159163.64	8.5E+0	6.5E+1	1.6E+2	2.7E+2	3.7E+2	4.7E+2	5.5E+2	6.2E+2	6.7E+2											
171896.73	6.0E+0	5.0E+1	1.3E+2	2.2E+2	3.1E+2	4.0E+2	4.7E+2	5.3E+2	5.9E+2	6.2E+2										
185648.47	4.3E+0	3.8E+1	1.0E+2	1.8E+2	2.6E+2	3.3E+2	4.0E+2	4.6E+2	5.1E+2	5.5E+2										
200500.34	3.0E+0	2.8E+1	7.8E+1	1.4E+2	2.1E+2	2.8E+2	3.4E+2	3.9E+2	4.4E+2	4.8E+2	5.2E+2									
216540.37	2.1E+0	2.1E+1	6.1E+1	1.1E+2	1.7E+2	2.3E+2	2.8E+2	3.4E+2	3.8E+2	4.2E+2	4.5E+2	4.9E+2								
233863.6	1.4E+0	1.5E+1	4.7E+1	9.0E+1	1.4E+2	1.9E+2	2.4E+2	2.8E+2	3.3E+2	3.6E+2	3.9E+2	4.3E+2	4.5E+2							
252572.69	9.7E-1	1.1E+1	3.6E+1	7.1E+1	1.1E+2	1.5E+2	2.0E+2	2.4E+2	2.8E+2	3.1E+2	3.4E+2	3.7E+2	3.9E+2	4.2E+2	4.3E+2					
272778.5	6.6E-1	8.3E+0	2.7E+1	5.5E+1	8.9E+1	1.3E+2	1.6E+2	2.0E+2	2.3E+2	2.6E+2	2.9E+2	3.2E+2	3.4E+2	3.6E+2	3.8E+2	4.0E+2				
294600.78	4.4E-1	6.0E+0	2.0E+1	4.3E+1	7.0E+1	1.0E+2	1.3E+2	1.6E+2	1.9E+2	2.2E+2	2.5E+2	2.7E+2	3.0E+2	3.2E+2	3.4E+2	3.5E+2	3.7E+2			
318168.85	2.9E-1	4.3E+0	1.5E+1	3.3E+1	5.5E+1	8.1E+1	1.1E+2	1.3E+2	1.6E+2	1.8E+2	2.1E+2	2.3E+2	2.5E+2	2.7E+2	2.9E+2	3.1E+2	3.2E+2	3.4E+2		
343622.35	1.9E-1	3.0E+0	1.1E+1	2.5E+1	4.3E+1	6.4E+1	8.6E+1	1.1E+2	1.3E+2	1.5E+2	1.8E+2	2.0E+2	2.2E+2	2.4E+2	2.5E+2	2.7E+2	2.8E+2	2.9E+2	3.1E+2	3.2E+2
371112.14	1.3E-1	2.1E+0	8.2E+0	1.9E+1	3.3E+1	5.0E+1	6.9E+1	8.9E+1	1.1E+2	1.3E+2	1.5E+2	1.7E+2	1.8E+2	2.0E+2	2.2E+2	2.3E+2	2.4E+2	2.6E+2	2.7E+2	2.8E+2
400801.11	8.3E-2	1.5E+0	6.0E+0	1.4E+1	2.5E+1	3.9E+1	5.5E+1	7.1E+1	8.8E+1	1.0E+2	1.2E+2	1.4E+2	1.5E+2	1.7E+2	1.8E+2	2.0E+2	2.1E+2	2.2E+2	2.3E+2	2.4E+2
432865.2	5.3E-2	1.0E+0	4.3E+0	1.1E+1	1.9E+1	3.0E+1	4.3E+1	5.7E+1	7.1E+1	8.5E+1	1.0E+2	1.2E+2	1.3E+2	1.4E+2	1.6E+2	1.7E+2	1.8E+2	1.9E+2	2.0E+2	2.1E+2
467494.42	3.4E-2	7.1E-1	3.1E+0	7.8E+0	1.5E+1	2.3E+1	3.4E+1	4.5E+1	5.7E+1	6.9E+1	8.2E+1	9.5E+1	1.1E+2	1.2E+2	1.3E+2	1.4E+2	1.5E+2	1.6E+2	1.7E+2	1.8E+2
504893.97	2.2E-2	4.9E-1	2.2E+0	5.7E+0	1.1E+1	1.8E+1	2.6E+1	3.5E+1	4.5E+1	5.5E+1	6.6E+1	7.7E+1	8.8E+1	9.9E+1	1.1E+2	1.2E+2	1.3E+2	1.4E+2	1.5E+2	1.6E+2
545285.49	1.4E-2	3.3E-1	1.6E+0	4.1E+0	8.1E+0	1.4E+1	2.0E+1	2.8E+1	3.6E+1	4.4E+1	5.3E+1	6.3E+1	7.2E+1	8.1E+1	9.0E+1	9.9E+1	1.1E+2	1.2E+2	1.2E+2	1.3E+2
588908.33	8.6E-3	2.2E-1	1.1E+0	3.0E+0	6.0E+0	1.0E+1	1.5E+1	2.1E+1	2.8E+1	3.5E+1	4.3E+1	5.0E+1	5.8E+1	6.6E+1	7.4E+1	8.2E+1	9.0E+1	9.7E+1	1.0E+2	1.1E+2
636021	5.3E-3	1.5E-1	7.6E-1	2.1E+0	4.4E+0	7.6E+0	1.2E+1	1.6E+1	2.2E+1	2.7E+1	3.4E+1	4.0E+1	4.7E+1	5.4E+1	6.1E+1	6.7E+1	7.4E+1	8.1E+1	8.7E+1	9.4E+1
686902.67	3.3E-3	9.7E-2	5.2E-1	1.5E+0	3.2E+0	5.6E+0	8.7E+0	1.2E+1	1.7E+1	2.1E+1	2.6E+1	3.2E+1	3.8E+1	4.3E+1	4.9E+1	5.5E+1	6.1E+1	6.7E+1	7.2E+1	7.8E+1
741854.89	2.0E-3	6.4E-2	3.6E-1	1.1E+0	2.3E+0	4.1E+0	6.5E+0	9.4E+0	1.3E+1	1.6E+1	2.1E+1	2.5E+1	3.0E+1	3.5E+1	3.9E+1	4.4E+1	5.0E+1	5.5E+1	5.9E+1	6.4E+1
801203.28	1.2E-3	4.2E-2	2.4E-1	7.5E-1	1.6E+0	3.0E+0	4.8E+0	7.1E+0	9.7E+0	1.3E+1	1.6E+1	2.0E+1	2.3E+1	2.7E+1	3.2E+1	3.6E+1	4.0E+1	4.4E+1	4.9E+1	5.3E+1
865299.54	7.2E-4	2.7E-2	1.6E-1	5.2E-1	1.2E+0	2.2E+0	3.5E+0	5.3E+0	7.3E+0	9.6E+0	1.2E+1	1.5E+1	1.8E+1	2.2E+1	2.5E+1	2.8E+1	3.2E+1	3.6E+1	3.9E+1	4.3E+1
934523.51	4.3E-4	1.7E-2	1.1E-1	3.6E-1	8.2E-1	1.6E+0	2.6E+0	3.9E+0	5.5E+0	7.2E+0	9.4E+0	1.2E+1	1.4E+1	1.7E+1	2.0E+1	2.3E+1	2.6E+1	2.9E+1	3.2E+1	3.5E+1
1009285.4	2.5E-4	1.1E-2	7.3E-2	2.4E-1	5.7E-1	1.1E+0	1.9E+0	2.8E+0	4.1E+0	5.4E+0	7.1E+0	8.9E+0	1.1E+1	1.3E+1	1.5E+1	1.8E+1	2.0E+1	2.3E+1	2.5E+1	2.8E+1
1090028.2	1.5E-4	6.9E-3	4.8E-2	1.6E-1	4.0E-1	7.8E-1	1.3E+0	2.1E+0	3.0E+0	4.0E+0	5.3E+0	6.8E+0	8.3E+0	1.0E+1	1.2E+1	1.4E+1	1.6E+1	1.8E+1	2.0E+1	2.2E+1
1177230.5	8.6E-5	4.3E-3	3.1E-2	1.1E-1	2.7E-1	5.5E-1	9.5E-1	1.5E+0	2.2E+0	3.0E+0	4.0E+0	5.1E+0	6.3E+0	7.7E+0	9.1E+0	1.1E+1	1.2E+1	1.4E+1	1.6E+1	1.8E+1
1271408.9	5.0E-5	2.7E-3	2.0E-2	7.4E-2	1.9E-1	3.8E-1	6.7E-1	1.1E+0	1.6E+0	2.2E+0	2.9E+0	3.8E+0	4.8E+0	5.8E+0	7.0E+0	8.2E+0	9.5E+0	1.1E+1	1.2E+1	1.4E+1
1373121.6	2.8E-5	1.6E-3	1.3E-2	4.9E-2	1.3E-1	2.6E-1	4.7E-1	7.6E-1	1.1E+0	1.6E+0	2.2E+0	2.8E+0	3.5E+0	4.4E+0	5.3E+0	6.2E+0	7.3E+0	8.4E+0	9.5E+0	1.1E+1
1482971.4	1.6E-5	1.0E-3	8.2E-3	3.2E-2	8.5E-2	1.8E-1	3.3E-1	5.4E-1	8.1E-1	1.1E+0	1.6E+0	2.1E+0	2.6E+0	3.3E+0	4.0E+0	4.7E+0	5.5E+0	6.4E+0	7.3E+0	8.3E+0
1601609.1	9.1E-6	6.0E-4	5.2E-3	2.1E-2	5.6E-2	1.2E-1	2.3E-1	3.7E-1	5.7E-1	8.2E-1	1.1E+0	1.5E+0	1.9E+0	2.4E+0	2.9E+0	3.5E+0	4.2E+0	4.9E+0	5.6E+0	6.4E+0
1729737.8	5.1E-6	3.6E-4	3.2E-3	1.3E-2	3.7E-2	8.2E-2	1.5E-1	2.6E-1	4.0E-1	5.8E-1	8.1E-1	1.1E+0	1.4E+0	1.8E+0	2.2E+0	2.6E+0	3.1E+0	3.7E+0	4.2E+0	4.9E+0
1868116.8	2.8E-6	2.2E-4	2.0E-3	8.6E-3	2.4E-2	5.5E-2	1.0E-1	1.8E-1	2.8E-1	4.1E-1	5.8E-1	7.8E-1	1.0E+0	1.3E+0	1.6E+0	1.9E+0	2.3E+0	2.7E+0	3.2E+0	3.7E+0
2017566.2	1.5E-6	1.3E-4	1.2E-3	5.5E-3	1.6E-2	3.6E-2	7.0E-2	1.2E-1	1.9E-1	2.8E-1	4.1E-1	5.6E-1	7.3E-1	9.3E-1	1.2E+0	1.4E+0	1.7E+0	2.0E+0	2.4E+0	2.8E+0
2178971.4	8.4E-7	7.5E-5	7.6E-4	3.4E-3	1.0E-2	2.4E-2	4.7E-2	8.3E-2	1.3E-1	2.0E-1	2.9E-1	3.9E-1	5.2E-1	6.7E-1	8.4E-1	1.0E+0	1.3E+0	1.5E+0	1.8E+0	2.0E+0
2353289.2	4.5E-7	4.3E-5	4.6E-4	2.2E-3	6.6E-3	1.6E-2	3.1E-2	5.6E-2	9.0E-2	1.4E-1	2.0E-1	2.8E-1	3.7E-1	4.8E-1	6.0E-1	7.5E-1	9.1E-1	1.1E+0	1.3E+0	1.5E+0
2541552.3	2.4E-7	2.5E-5	2.8E-4	1.3E-3	4.2E-3	1.0E-2	2.0E-2	3.7E-2	6.1E-2	9.3E-2	1.4E-1	1.9E-1	2.6E-1	3.4E-1	4.3E-1	5.4E-1	6.6E-1	7.9E-1	9.4E-1	1.1E+0

As an example of applying the Π_{HAST} factor, consider the following situation:

1. HAST testing was performed at 145°C and 90% RH, and the mean life of the lognormal distribution was 1700 hours.
2. The failure rate over a three year time period is desired.

The following steps are required to calculate the environmental failure rate multiplying factor (Π_{HAST}):

1. Calculate the observed mean lifetime from HAST tests at the 48°C, 40% RH conditions.

$$\mu_{(48,40)} = \mu_{HAST} \frac{\Pi_{RHT(145,90)}}{\Pi_{RHT(48,40)}}$$

$$\mu_{HAST} = 1700 \text{ hours}$$

$$\Pi_{RHT(145°C,90\%RH)} = 260$$

$$\Pi_{RHT(48°C,\ 40\%\ RH)} = 1.29$$

$$\mu_{(48,40)} = 1700\left(\frac{260}{1.29}\right) = \ 342{,}635$$

2. Determine the multiplier at 3 years from Table 6.5-1. In this case it is 11.

Figure 6.5-1, on a linear scale, illustrates the Π_{HAST} factor as a function of HAST mean life times the Π_{RHT} for the HAST conditions, and time. Figure 6.5-2 illustrates the same data on a log scale.

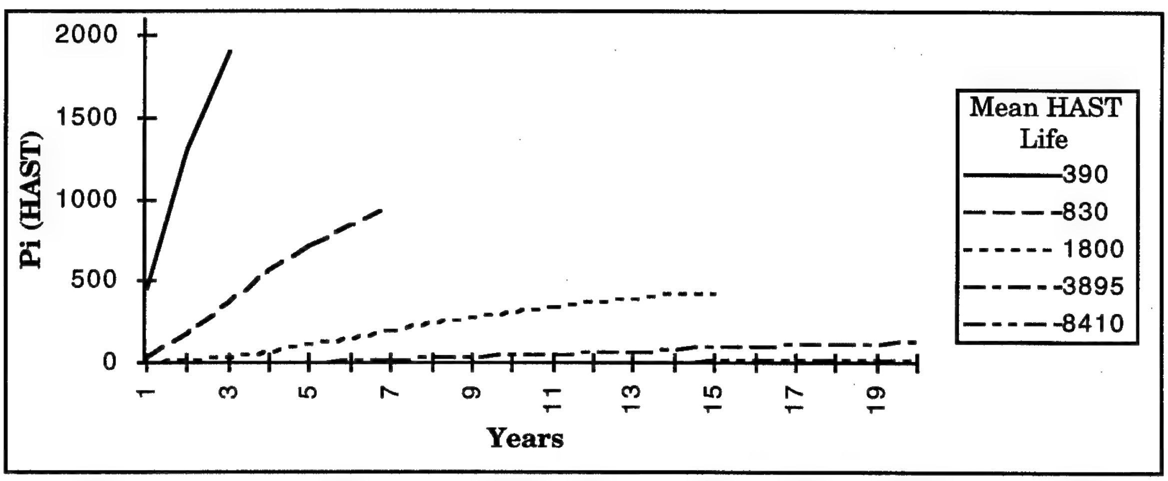

FIGURE 6.5-1: Pi (HAST) VS. HAST MEAN LIFE AND YEARS ON LINEAR SCALE

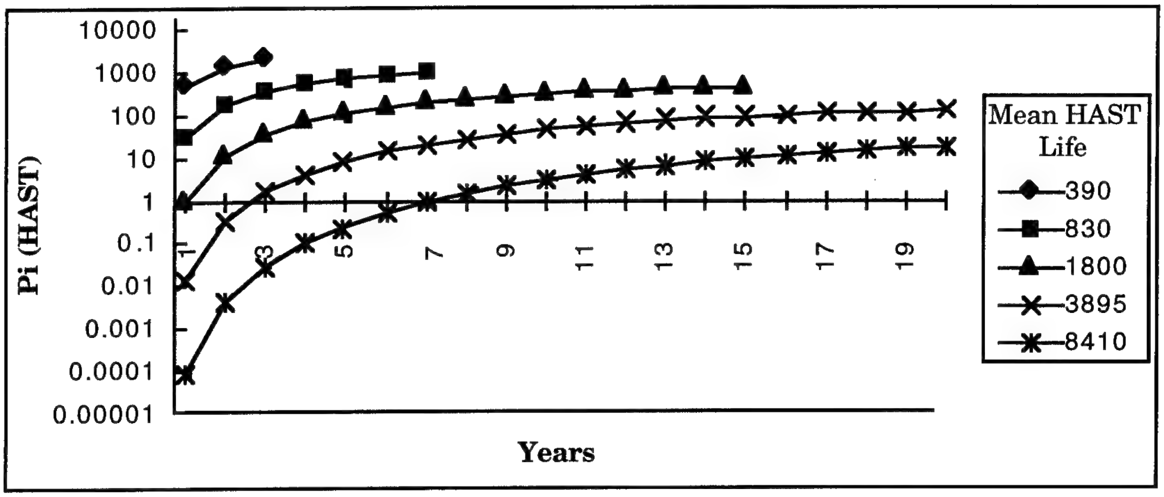

FIGURE 6.5-2: Pi (HAST) VS. HAST MEAN LIFE AND YEARS ON LOG SCALE

6.6 Temperature Cycling Failure Rate

The failure rate due to temperature cycling was then modeled using the following model form:

$$\lambda_{TC} = \lambda_{BTC}\Pi_{TC}\Pi_{TYPE}\Pi_{CR}\Pi_{TCT}$$

where,

λ_{BTC} is the base failure rate, in failures per million calendar hours, from temperature cycling to be derived from the data.

Π_{TC} is the failure rate acceleration factor as a function of the temperature extremes.

Π_{CR} is the cycling rate factor $\left(\frac{CR}{123138}\right)$, which converts the failure rate life unit to cycles. CR is in cycles per million calendar hours.

Π_{TCT} is the tailoring factor as a function of the total temperature change.

$$\Pi_{TC} = \left(\frac{\Delta T}{46.13}\right)^4$$

where,

ΔT is the change in device temperature between operating and dormant states. Its value is:

$$\Delta T = T_{Ao} + T_R - T_{AE}$$

where,

T_{Ao} = Ambient operating temperature
T_R = Temperature rise from power dissipation
T_{AE} = Ambient environmental temperature during nonoperation

The constant 46.13 is the geometric mean of the ΔT values of the data used. The exponent constant of 4 is a ductile model and will be used in this model.

The value of λ_{BTC} was determined by taking the geometric mean of the values required to equate the observed and predicted failure rates. This value was calculated to be .00099.

Therefore, the temperature cycling failure rate portion of the model is:

$$\lambda_{TC} = .00099\Pi_{TYPE}\left(\frac{\Delta T}{46.13}\right)^4\left(\frac{CR}{123138}\right)\Pi_{TCT}$$

6.6.1 Temperature Cycling Tailoring Factor

The temperature cycling mean cycles to failure plot presented previously (Figure 5.7-2) represents the distribution of characteristic lives. A simulation indicates that the mean and standard deviation of the distribution of cycles-to-failure for the entire population are 4158 cycles and 2.24, respectively.

The average predicted life of PEMs based on the average field use conditions is:

$$\mu_{use} = \frac{\Pi_{TC(215)}}{\Pi_{TC(46)}}\mu_{test}$$

where,

$\Pi_{TC(215)}$ is the temperature cycling acceleration factor for the average test conditions of $\Delta T = 215$:

$$\Pi_{TC(215)} = \left(\frac{215}{46}\right)^4 = 472$$

$\Pi_{TC(46)}$ is the temperature cycling acceleration factor under average field use conditions:

$$\Pi_{TC(46)} = \left(\frac{46}{46}\right)^4 = 1$$

μ_{test} is the mean cycle life under test conditions = 4158 cycles.

Therefore,

$$\mu_{use} = 4158\ (472) = 1{,}962{,}576 \text{ cycles}$$

There is a relatively high degree of uncertainty in these values, due primarily to the fact that most of the empirical data was based on tests terminated at approximately 1000 cycles, and that there were typically very small cumulative percent failures at 1000 cycles. Extrapolating such data to mean-cycles-to-failure results in uncertain estimates.

A cumulative percent failure was calculated using a mean life of 1.96 x 10^6 cycles, a standard deviation of 2.24, time intervals from one through twenty years, and an average cycling rate of 123,138 cycles/10^6 calendar hours. The predicted percent failure under these conditions is so small as to be insignificant, indicating that either the temperature cycling acceleration factor is in error, the estimate of MTTF is in error, or that the failure mechanisms occurring in the field are not following the lognormal distribution that is represented by the test data. The latter is a more likely explanation for several reasons: (1) the observed field failure rates decrease over time instead of increasing, indicating that the failures are due to defects which fail earlier than the main population of parts, and (2) the population statistics break down at the extreme tails of the distribution. These observations indicate that there is a more constant failure rate (in failures per million cycles) than is indicated by the time to failure characteristics of the main population. Therefore, the failure rate multiplier as a function of empirical temperature cycling data Π_{TCT} will be:

$$\Pi_{TCT} = \frac{(\%\ \text{Fail}/1000\ \text{cycles})}{.43}\left(\frac{215}{\Delta T}\right)^4$$

where,

(% Fail/1000 Cycles) is the percent of the population failing at 1000 cycles. For example, if the test is terminated at 500 cycles, the percentage must be multiplied by two to obtain Failures/1000 Cycles.

$\left(\frac{215}{\Delta T}\right)^4$ is the acceleration factor as a function of the temperature extremes.

ΔT is the total change in ambient temperature to which the PEMs were exposed during test.

.43% is a normalization constant which is the mean observed percent failure/1000 cycles at a $\Delta T = 215°C$.

This factor equals one under the average conditions of $\Delta T = 215°C$ and % Fail/1000 hrs. = .43.

6.7 <u>Growth Factor</u> (Π_G)

Since all data collected indicates that the failure rate of PEMs is decreasing over time, the relationship of failure rate vs. year was determined by fitting the failure rate data as a function of year to the following equation:

$$\lambda(t) = Ae^{-B(t-1992)}$$

where,

A,B are regression constants
t is the year of PEM manufacture

The constant B is the reliability growth rate. The higher its value, the more rapid the failure rate is decreasing. The year 1992 was chosen for the baseline because it was the year for which most of the field data was collected. Data was available from approximately 1980 to 1992, depending on the particular data source.

Table 6.7-1 summarizes the observed failure rates (relative to 1992) and the growth rate, B, as a function of environment, laboratory vs. field, component type, and die vs. package (life test only).

TABLE 6.7-1: RELIABILITY GROWTH RATES

Data Type/Environment	Component Type/Failure Mode	Base Failure Rate (relative to 1992)	Growth Rate (B)
Field/Airborne	Linear Digital SSI/MSI Microprocessor/Memory	.054 .010 .14	N/A[1]
Field/Automotive (underhood)	Linear Digital SSI/MSI Microprocessor/Memory	.32 .11 .13	-.197 -.513 -.526
Field/Ground Benign	Linear Digital (SSI/MSI) Microprocessor/Memory	.0030 .00097 .0023	-.437
Life Test/125°C and 150°C	All Failure Modes Package Failure Modes Only	.608 .0989	-.172 -.247

Note 1: Failure rate data was not available as a function of year for this data source.

6.8 PEM Failure Rate Model Summary

If none of the tailoring factors are used, the fundamental parameters necessary to estimate the reliability of a PEM are:

Device Type - Categorization of the device type into either the linear, digital SSI/MSI, or memory/microprocessor categories.

Ambient Operating Temperature (T_{AO}) - The average ambient temperature within the vicinity of the PEM while the system is in operation.

Ambient Environmental Temperature (T_{AE}) - The ambient temperature within the vicinity of the PEM while the system is non-operating.

Temperature Rise ($T_R = \theta_{JA} P$) - The temperature rise associated with power dissipation. Equal to the thermal resistance (θ_{JA}) times power (P).

Duty Cycle (DC) - The percentage of calendar time that the system is in operation, expressed in decimal form.

Relative Humidity (RH) - The average ambient relative humidity to the PEM expressed in decimal form.

Cycling Rate (CR) - The rate (in cycles per million calendar hours) at which the power is cycled, equivalent to the number of on-off cycles in 10^6 hours.

The complete model is as follows:

$$\lambda_P = \Pi_{TYPE}[\lambda_{BO}\Pi_T\Pi_{DC}\Pi_{LT} + \lambda_{BE}\Pi_{RHT}\Pi_{HAST} + \lambda_{BTC}\Pi_{TC}\Pi_{CR}\Pi_{TCT}]\Pi_G$$

where,

λ_p = Predicted failure rate in failures per million calendar hours

Π_{TYPE} = Device Type Factor
= 1.0 for Digital Devices (SSI/MSI)
= 3.65 for Linear Devices
= 3.40 for Memory and Microprocessors

λ_{BO} = Base Operating Die Failure Rate
= 3.05×10^{-6} Failures/10^6 calendar hours (F/10^6CH)

Π_T = Operating Temperature Factor

$$= \exp\left[-\frac{.8}{8.617 \times 10^{-5}}\left(\frac{1}{T_J} - \frac{1}{298}\right)\right]$$

where,

T_J = Junction Operating Temperature in °K (°C + 273)
= $T_{AO} + T_R$

where,

$T_R = Q_{JA}P$
$= T_{AO} + \theta_{JA}P$
T_{AO} = Ambient Operating Temperature
θ_{JA} = Junction - Ambient Thermal Resistance
P = Power

$$\Pi_{DC} = \frac{DC}{.17}$$

where,

$$DC = \text{Duty Cycle} = \frac{\text{Operating Time}}{\text{Calendar Time}}$$

Π_{LT} = Tailoring Factor as a function of high temperature operating life test on the specific part being predicted

= 1 if no life test data is available

$$= \left(\frac{\lambda_{life}}{.608}\right) \bullet \left(\frac{13335}{\Pi_{T(life)}}\right) \text{ if data is available}$$

where,

λ_{life} = Observed life test operational failure rate(in f/10^6 op-hours)

$$= \frac{\text{Total Number of Failures}}{\text{Cumulative Number of Part Hours}}\left(x10^6\right)$$

$\Pi_{T(life)}$ = Operating Temperature Factor (Π_T) for life test conditions

λ_{BE} = Base Environmental Failure Rate (F/10^6CH)
= .00046 F/10^6CH

Π_{RHT} = Acceleration Factor as a function of Environmental Effective Relative Humidity (RH_{eff}) and Temperature

$$= \exp\left[\frac{-.34}{8.617 \times 10^{-5}}\left(\frac{1}{T_{AE}}-\frac{1}{298}\right)\right]\left(\frac{RH_{eff}}{.5}\right)^3$$

where,

T_{AE} = Environment Ambient Temperature (in °K)
RH_{eff} = Effective Relative Humidity

$$= (DC)(RH)\exp\left[5230\left(\frac{1}{T_J}-\frac{1}{T_{AE}}\right)\right] + (1-DC)(RH)$$

where,

RH = Ambient Average Relative Humidity

Π_{HAST} = Tailoring Factor as a Function of HAST Data on the Specific Part Being Predicted

= 1 if no HAST data is available

Table 6.8-1 contains the Π_{HAST} values as a function of the predicted mean time to failure and the time period (in years) over which the average failure rate is to be predicted. The Mean Time To Failure (μ) is:

$$\mu = \mu_{HAST}\frac{\Pi_{RHT(HAST)}}{1.29}$$

where,

μ_{HAST} = The observed MTTF from HAST Testing from the lognormal Distribution

TABLE 6.8-1: Π_{HAST} VS. HAST MEAN LIFE AND TIME

	Years																			
μ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
25100	3.1E+3																			
27108	2.7E+3																			
29276.64	2.3E+3																			
31618.771	1.9E+3																			
34148.273	1.6E+3	3.2E+3																		
36880.135	1.3E+3	2.8E+3																		
39830.546	1.1E+3	2.5E+3																		
43016.989	8.7E+2	2.1E+3																		
46458.348	7.1E+2	1.8E+3																		
50175.016	5.7E+2	1.6E+3																		
54189.017	4.5E+2	1.3E+3	1.9E+3																	
58524.139	3.6E+2	1.1E+3	1.7E+3																	
63206.07	2.8E+2	9.5E+2	1.5E+3																	
68262.556	2.2E+2	7.9E+2	1.3E+3	1.6E+3																
73723.56	1.7E+2	6.5E+2	1.1E+3	1.4E+3																
79621.445	1.3E+2	5.4E+2	9.3E+2	1.2E+3																
85991.16	9.9E+1	4.4E+2	7.9E+2	1.1E+3	1.3E+3															
92870.453	7.5E+1	3.5E+2	6.6E+2	9.2E+2	1.1E+3															
100300.09	5.6E+1	2.8E+2	5.5E+2	7.9E+2	9.7E+2	1.1E+3														
108324.1	4.2E+1	2.3E+2	4.6E+2	6.7E+2	8.4E+2	9.7E+2														
116990.02	3.1E+1	1.8E+2	3.8E+2	5.7E+2	7.2E+2	8.5E+2	9.4E+2													
126349.23	2.3E+1	1.4E+2	3.1E+2	4.8E+2	6.2E+2	7.4E+2	8.3E+2													
136457.16	1.6E+1	1.1E+2	2.5E+2	4.0E+2	5.3E+2	6.4E+2	7.3E+2	8.0E+2												
147373.74	1.2E+1	8.5E+1	2.0E+2	3.3E+2	4.4E+2	5.5E+2	6.3E+2	7.0E+2												
159163.64	8.5E+0	6.5E+1	1.6E+2	2.7E+2	3.7E+2	4.7E+2	5.5E+2	6.2E+2	6.7E+2											
171896.73	6.0E+0	5.0E+1	1.3E+2	2.2E+2	3.1E+2	4.0E+2	4.7E+2	5.3E+2	5.9E+2	6.2E+2										
185648.47	4.3E+0	3.8E+1	1.0E+2	1.8E+2	2.6E+2	3.3E+2	4.0E+2	4.6E+2	5.1E+2	5.5E+2										
200500.34	3.0E+0	2.8E+1	7.8E+1	1.4E+2	2.1E+2	2.8E+2	3.4E+2	3.9E+2	4.4E+2	4.8E+2	5.2E+2									
216540.37	2.1E+0	2.1E+1	6.1E+1	1.1E+2	1.7E+2	2.3E+2	2.8E+2	3.4E+2	3.8E+2	4.2E+2	4.5E+2	4.9E+2								
233863.6	1.4E+0	1.5E+1	4.7E+1	9.0E+1	1.4E+2	1.9E+2	2.4E+2	2.8E+2	3.3E+2	3.6E+2	3.9E+2	4.3E+2	4.5E+2							
252572.69	9.7E-1	1.1E+1	3.6E+1	7.1E+1	1.1E+2	1.5E+2	2.0E+2	2.4E+2	2.8E+2	3.1E+2	3.4E+2	3.7E+2	3.9E+2	4.2E+2	4.3E+2					
272778.5	6.6E-1	8.3E+0	2.7E+1	5.5E+1	8.9E+1	1.3E+2	1.6E+2	2.0E+2	2.3E+2	2.6E+2	2.9E+2	3.2E+2	3.4E+2	3.6E+2	3.8E+2	4.0E+2				
294600.78	4.4E-1	6.0E+0	2.0E+1	4.3E+1	7.0E+1	1.0E+2	1.3E+2	1.6E+2	1.9E+2	2.2E+2	2.5E+2	2.7E+2	3.0E+2	3.2E+2	3.4E+2	3.5E+2	3.7E+2			
318168.85	2.9E-1	4.3E+0	1.5E+1	3.3E+1	5.5E+1	8.1E+1	1.1E+2	1.3E+2	1.6E+2	1.8E+2	2.1E+2	2.3E+2	2.5E+2	2.7E+2	2.9E+2	3.1E+2	3.2E+2	3.4E+2		
343622.35	1.9E-1	3.0E+0	1.1E+1	2.5E+1	4.3E+1	6.4E+1	8.6E+1	1.1E+2	1.3E+2	1.5E+2	1.8E+2	2.0E+2	2.2E+2	2.4E+2	2.5E+2	2.7E+2	2.8E+2	2.9E+2	3.1E+2	3.2E+2
371112.14	1.3E-1	2.1E+0	8.2E+0	1.9E+1	3.3E+1	5.0E+1	6.9E+1	8.9E+1	1.1E+2	1.3E+2	1.5E+2	1.7E+2	1.8E+2	2.0E+2	2.2E+2	2.3E+2	2.4E+2	2.6E+2	2.7E+2	2.8E+2
400801.11	8.3E-2	1.5E+0	6.0E+0	1.4E+1	2.5E+1	3.9E+1	5.5E+1	7.1E+1	8.8E+1	1.0E+2	1.2E+2	1.4E+2	1.5E+2	1.7E+2	1.8E+2	2.0E+2	2.1E+2	2.2E+2	2.3E+2	2.4E+2
432865.2	5.3E-2	1.0E+0	4.3E+0	1.1E+1	1.9E+1	3.0E+1	4.3E+1	5.7E+1	7.1E+1	8.5E+1	1.0E+2	1.2E+2	1.3E+2	1.4E+2	1.6E+2	1.7E+2	1.8E+2	1.9E+2	2.0E+2	2.1E+2
467494.42	3.4E-2	7.1E-1	3.1E+0	7.8E+0	1.5E+1	2.3E+1	3.4E+1	4.5E+1	5.7E+1	6.9E+1	8.2E+1	9.5E+1	1.1E+2	1.2E+2	1.3E+2	1.4E+2	1.5E+2	1.6E+2	1.7E+2	1.8E+2
504893.97	2.2E-2	4.9E-1	2.2E+0	5.7E+0	1.1E+1	1.8E+1	2.6E+1	3.5E+1	4.5E+1	5.5E+1	6.6E+1	7.7E+1	8.8E+1	9.9E+1	1.1E+2	1.2E+2	1.3E+2	1.4E+2	1.5E+2	1.6E+2
545285.49	1.4E-2	3.3E-1	1.6E+0	4.1E+0	8.1E+0	1.4E+1	2.0E+1	2.8E+1	3.6E+1	4.4E+1	5.3E+1	6.3E+1	7.2E+1	8.1E+1	9.0E+1	9.9E+1	1.1E+2	1.2E+2	1.2E+2	1.3E+2
588908.33	8.6E-3	2.2E-1	1.1E+0	3.0E+0	6.0E+0	1.0E+1	1.5E+1	2.1E+1	2.8E+1	3.5E+1	4.3E+1	5.0E+1	5.8E+1	6.6E+1	7.4E+1	8.2E+1	9.0E+1	9.7E+1	1.0E+2	1.1E+2
636021	5.3E-3	1.5E-1	7.6E-1	2.1E+0	4.4E+0	7.6E+0	1.2E+1	1.6E+1	2.2E+1	2.7E+1	3.4E+1	4.0E+1	4.7E+1	5.4E+1	6.1E+1	6.7E+1	7.4E+1	8.1E+1	8.7E+1	9.4E+1
686902.67	3.3E-3	9.7E-2	5.2E-1	1.5E+0	3.2E+0	5.6E+0	8.7E+0	1.2E+1	1.7E+1	2.1E+1	2.6E+1	3.2E+1	3.8E+1	4.3E+1	4.9E+1	5.5E+1	6.1E+1	6.7E+1	7.2E+1	7.8E+1
741854.89	2.0E-3	6.4E-2	3.6E-1	1.1E+0	2.3E+0	4.1E+0	6.5E+0	9.4E+0	1.3E+1	1.6E+1	2.1E+1	2.5E+1	3.0E+1	3.5E+1	3.9E+1	4.4E+1	5.0E+1	5.5E+1	5.9E+1	6.4E+1
801203.28	1.2E-3	4.2E-2	2.4E-1	7.5E-1	1.6E+0	3.0E+0	4.8E+0	7.1E+0	9.7E+0	1.3E+1	1.6E+1	2.0E+1	2.3E+1	2.7E+1	3.2E+1	3.6E+1	4.0E+1	4.4E+1	4.9E+1	5.3E+1
865299.54	7.2E-4	2.7E-2	1.6E-1	5.2E-1	1.2E+0	2.2E+0	3.5E+0	5.3E+0	7.3E+0	9.6E+0	1.2E+1	1.5E+1	1.8E+1	2.2E+1	2.5E+1	2.8E+1	3.2E+1	3.6E+1	3.9E+1	4.3E+1
934523.51	4.3E-4	1.7E-2	1.1E-1	3.6E-1	8.2E-1	1.6E+0	2.6E+0	3.9E+0	5.5E+0	7.2E+0	9.4E+0	1.2E+1	1.4E+1	1.7E+1	2.0E+1	2.3E+1	2.6E+1	2.9E+1	3.2E+1	3.5E+1
1009285.4	2.5E-4	1.1E-2	7.3E-2	2.4E-1	5.7E-1	1.1E+0	1.9E+0	2.8E+0	4.1E+0	5.4E+0	7.1E+0	8.9E+0	1.1E+1	1.3E+1	1.5E+1	1.8E+1	2.0E+1	2.3E+1	2.5E+1	2.8E+1
1090028.2	1.5E-4	6.9E-3	4.8E-2	1.6E-1	4.0E-1	7.8E-1	1.3E+0	2.1E+0	3.0E+0	4.0E+0	5.3E+0	6.8E+0	8.3E+0	1.0E+1	1.2E+1	1.4E+1	1.6E+1	1.8E+1	2.0E+1	2.2E+1
1177230.5	8.6E-5	4.3E-3	3.1E-2	1.1E-1	2.7E-1	5.5E-1	9.5E-1	1.5E+0	2.2E+0	3.0E+0	4.0E+0	5.1E+0	6.3E+0	7.7E+0	9.1E+0	1.1E+1	1.2E+1	1.4E+1	1.6E+1	1.8E+1
1271408.9	5.0E-5	2.7E-3	2.0E-2	7.4E-2	1.9E-1	3.8E-1	6.7E-1	1.1E+0	1.6E+0	2.2E+0	2.9E+0	3.8E+0	4.8E+0	5.8E+0	7.0E+0	8.2E+0	9.5E+0	1.1E+1	1.2E+1	1.4E+1
1373121.6	2.8E-5	1.6E-3	1.3E-2	4.9E-2	1.3E-1	2.6E-1	4.7E-1	7.6E-1	1.1E+0	1.6E+0	2.2E+0	2.8E+0	3.5E+0	4.4E+0	5.3E+0	6.2E+0	7.3E+0	8.4E+0	9.5E+0	1.1E+1
1482971.4	1.6E-5	1.0E-3	8.2E-3	3.2E-2	8.5E-2	1.8E-1	3.3E-1	5.4E-1	8.1E-1	1.1E+0	1.6E+0	2.1E+0	2.6E+0	3.3E+0	4.0E+0	4.7E+0	5.5E+0	6.4E+0	7.3E+0	8.3E+0
1601609.1	9.1E-6	6.0E-4	5.2E-3	2.1E-2	5.6E-2	1.2E-1	2.3E-1	3.7E-1	5.7E-1	8.2E-1	1.1E+0	1.5E+0	1.9E+0	2.4E+0	2.9E+0	3.5E+0	4.2E+0	4.9E+0	5.6E+0	6.4E+0
1729737.8	5.1E-6	3.6E-4	3.2E-3	1.3E-2	3.7E-2	8.2E-2	1.5E-1	2.6E-1	4.0E-1	5.8E-1	8.1E-1	1.1E+0	1.4E+0	1.8E+0	2.2E+0	2.6E+0	3.1E+0	3.7E+0	4.2E+0	4.9E+0
1868116.8	2.8E-6	2.2E-4	2.0E-3	8.6E-3	2.4E-2	5.5E-2	1.0E-1	1.8E-1	2.8E-1	4.1E-1	5.8E-1	7.8E-1	1.0E+0	1.3E+0	1.6E+0	1.9E+0	2.3E+0	2.7E+0	3.2E+0	3.7E+0
2017566.2	1.5E-6	1.3E-4	1.2E-3	5.5E-3	1.6E-2	3.6E-2	7.0E-2	1.2E-1	1.9E-1	2.8E-1	4.1E-1	5.6E-1	7.3E-1	9.3E-1	1.2E+0	1.4E+0	1.7E+0	2.0E+0	2.4E+0	2.8E+0
2178971.4	8.4E-7	7.5E-5	7.6E-4	3.4E-3	1.0E-2	2.4E-2	4.7E-2	8.3E-2	1.3E-1	2.0E-1	2.9E-1	3.9E-1	5.2E-1	6.7E-1	8.4E-1	1.0E+0	1.3E+0	1.5E+0	1.8E+0	2.0E+0
2353289.2	4.5E-7	4.3E-5	4.6E-4	2.2E-3	6.6E-3	1.6E-2	3.1E-2	5.6E-2	9.0E-2	1.4E-1	2.0E-1	2.8E-1	3.7E-1	4.8E-1	6.0E-1	7.5E-1	9.1E-1	1.1E+0	1.3E+0	1.5E+0
2541552.3	2.4E-7	2.5E-5	2.8E-4	1.3E-3	4.2E-3	1.0E-2	2.0E-2	3.7E-2	6.1E-2	9.3E-2	1.4E-1	1.9E-1	2.6E-1	3.4E-1	4.3E-1	5.4E-1	6.6E-1	7.9E-1	9.4E-1	1.1E+0

$\Pi_{RHT(HAST)}$ = Acceleration Factor under the HAST Test Conditions

λ_{BTC} = Base Temperature Cycling Failure Rate
= .00099 F/10^6CH

Π_{TC} = Acceleration Factor as a Function of Temperature Extremes

$$= \left(\frac{\Delta T}{46.1}\right)^4$$

where,

$$\Delta T = T_{AO} + T_R - T_{AE}\ (°C)$$

where,

T_{AO} = Operating Ambient Temperature (°C)
T_R = Temperature Rise
= $\theta_{JC}P$
T_{AE} = Ambient Environmental Temperature during Non-operation

Π_{CR} = Cycling Rate Factor

$$= \frac{CR}{123138}$$

where,

CR = Number of Expected Temperature Cycles of Magnitude ΔT per 10^6 calendar hours.

Π_{TCT} = Tailoring Factor as a function of Temperature Cycling Tests.

= 1, if no temperature cycling data is available

$$= \frac{1}{.43}(\%\text{ Fail / 1000 cycles})\left(\frac{215}{\Delta T_T}\right)^4$$, if temperature cycling data is available

where,

% Fail/1000 Cycles = population percentage failing at 1000 temperature cycles (i.e., Failures/Population x 100)

ΔT_T = Change in Temperature during Temperature Cycling Tests

Π_G = Growth Factor as a Function of Year of Manufacture

= 1, if any empirical data was used to tailor the prediction using Π_{LT}, Π_{HAST}, or Π_{TCT}

$= \exp[-B(t-1992)]$

where,

B = .293 For linear devices
= .473 For Digital SS1/MS1
= .479 For memory/microprocessors

6.9 Prediction Example

As an example of using the PEM model, consider the following conditions:

Device Type = Microprocessor
Ambient Operating Temperature(T_{AO}) = 40°C
Temperature Rise (T_R) = 20°C
Duty Cycle (DC) = 30%
Ambient Environmental Temp (T_{AE}) = 25°C
Relative Humidity = 60%
Cycling Rate (CR) = 175,000 cycles/10^6 calendar hours
Year = 1992

$$\lambda_P = \Pi_{TYPE}\left[\lambda_{BO}\Pi_T\left(\frac{\Pi_{DC}}{.17}\right)\Pi_{LT} + \lambda_{BE}\Pi_{RHT}\Pi_{HAST} + \lambda_{BTC}\Pi_{TC}\Pi_{CR}\Pi_{TCT}\right]\Pi_G$$

Π_{TYPE} = 3.4

λ_{BO} = .00000305

$$\Pi_T = \exp\left(\frac{-.8}{8.617\text{x}10^{-5}}\left(\frac{1}{40+20+273}\right)-\left(\frac{1}{298}\right)\right) = 26.43$$

$$\Pi_{DC} = \frac{DC}{.17} = \frac{.30}{.17} = 1.765$$

Π_{LT} = 1 (No available life test data)

λ_{BE} = .00046

$$\Pi_{RHT} = \exp\left[\frac{-.34}{8.617\text{x}10^{-5}}\left(\frac{1}{25+273}-\frac{1}{298}\right)\right]\left[\frac{RH_{eff}}{.5}\right]^3$$

$$RH_{eff} = (DC)\,(RH)\exp\left[5230\left(\frac{1}{T_J}-\frac{1}{T_{AO}}\right)\right]+(1-DC)\,(RH)$$

$$= (.30)\,(.60)\,\exp\left[5230\left(\left(\frac{1}{40+20+273}\right)-\left(\frac{1}{40+273}\right)\right)\right]+(.7)\,(.6) = .486$$

Π_{RHT} = .918

Π_{HAST} = 1 (No HAST data available)

λ_{BTC} = .00099

$$\Pi_{TC} = \left(\frac{\Delta T}{46.1}\right)^4$$

$$\Delta T = T_{AO} + T_R - T_{AE}$$
$$= 40 + 20 - 25$$
$$= 35°C$$

$$\Pi_{TC} = \left(\frac{35}{46.1}\right)^4 = .332$$

$$\Pi_{CR} = \frac{CR}{123138} = \frac{175{,}000}{123{,}138} = 1.421$$

Π_{TCT} = 1 (No temperature cycling test data available)

$$\Pi_G = \exp[-B(t-1992)]$$

For $t = 1992$,

$$\Pi_G = \exp[-.479(1992-1992)]$$
$$= 1$$

Therefore, the predicted failure rate is:

$$\lambda_P = 3.4[(.00000305)(26.43)(1.765)(1) + (.00046)(.918)(1) + (.00099)(.332)(1.421)(1)](1)$$
$$= .0035 \text{ Failures}/10^6 \text{ CH}$$

The model was also exercised holding all but one variable constant and varying that one parameter over a predefined range. Two sets of conditions given in Table 6.9-1 were used, a severe set and a benign set. In all examples, the tailoring factors are not applied, the device type used was a microprocessor, and the year on which the prediction is based is 1992.

TABLE 6.9-1: STRESSES USED FOR EXAMPLE CALCULATION

Stress	Symbol	Severe Condition Value	Benign Condition Value
Ambient Operating Temp	T_{AO}(°C)	80	30
Temperature Rise	T_R(°C)	50	5
Duty Cycle	DC(°C)	5	30
Ambient Environmental Temp	T_{AE}(°C)	70	15
Relative Humidity	RH(°C)	90	10
Cycling Rate	CR Cycles/10^6 CH	500,000	50,000

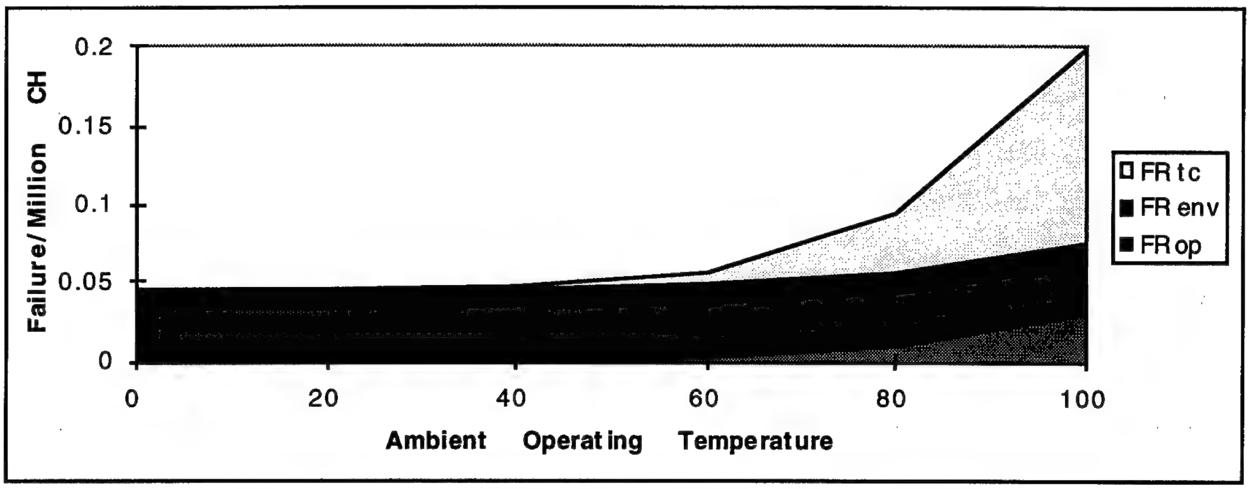

FIGURE 6.9-1: FAILURE RATE VS AMBIENT OPERATING TEMPERATURE FOR SEVERE STRESSES

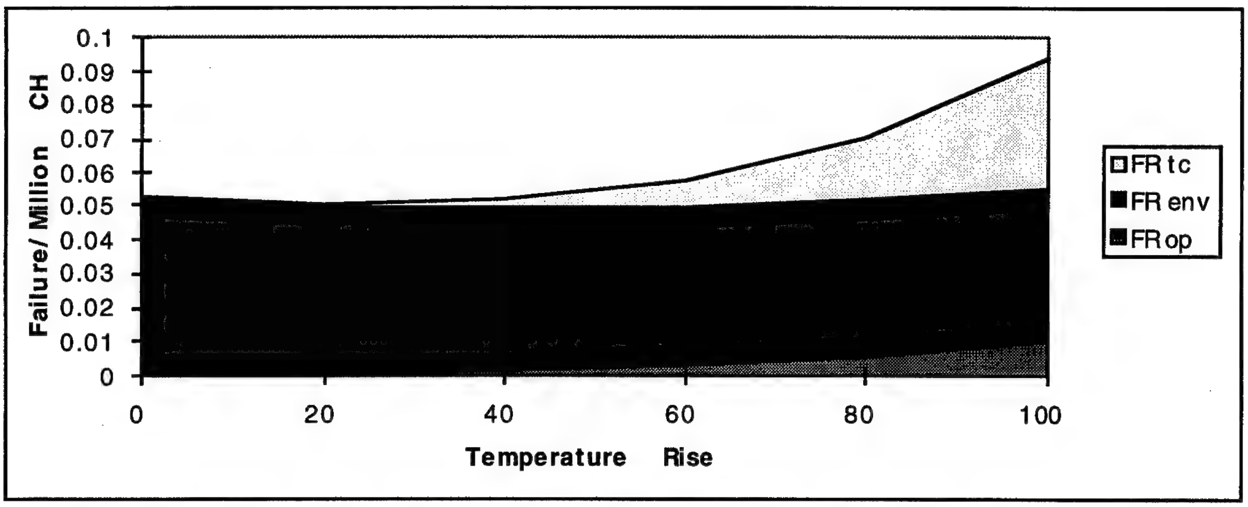

FIGURE 6.9-2: FAILURE RATE VS TEMPERATURE RISE FOR SEVERE STRESSES

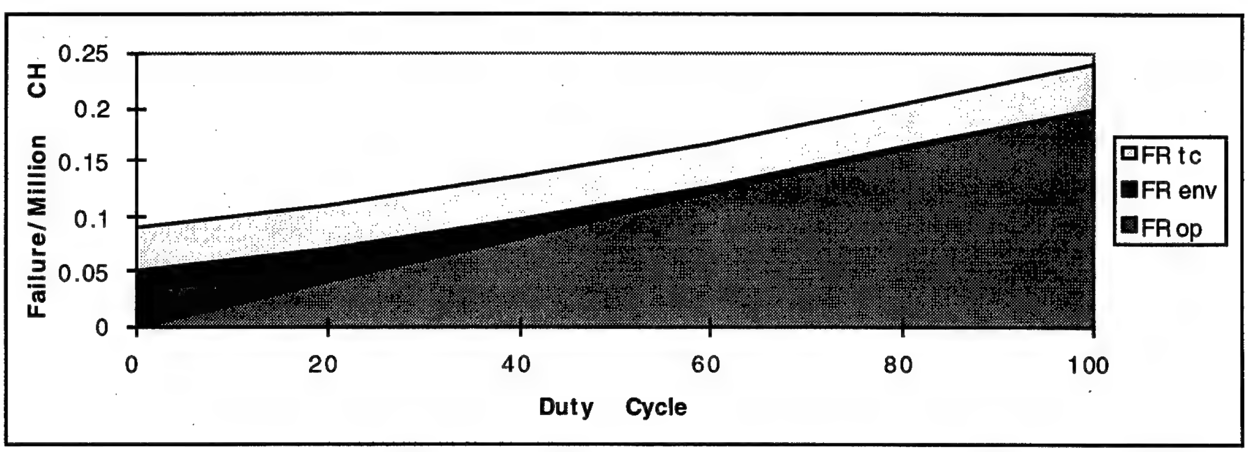

FIGURE 6.9-3: FAILURE RATE VS DUTY CYCLE FOR SEVERE STRESSES

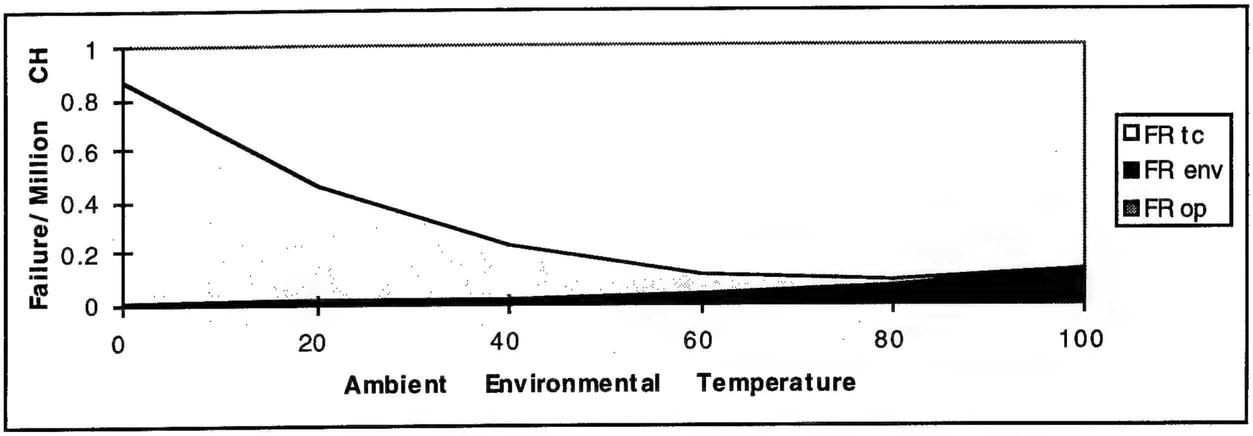

FIGURE 6.9-4: FAILURE RATE VS AMBIENT ENVIRONMENTAL TEMPERATURE FOR SEVERE STRESSES

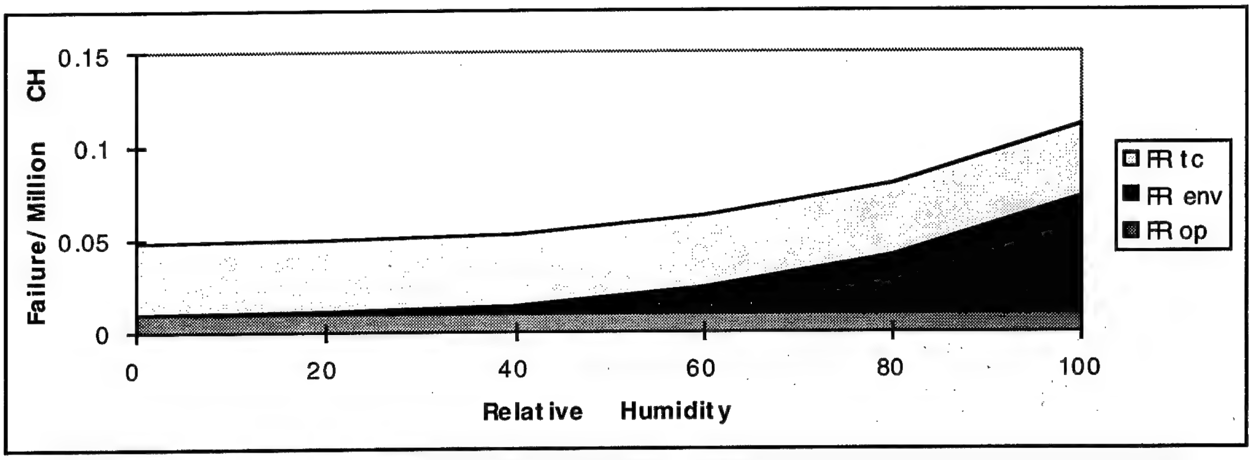

FIGURE 6.9-5: FAILURE RATE VS RELATIVE HUMIDITY FOR SEVERE STRESSES

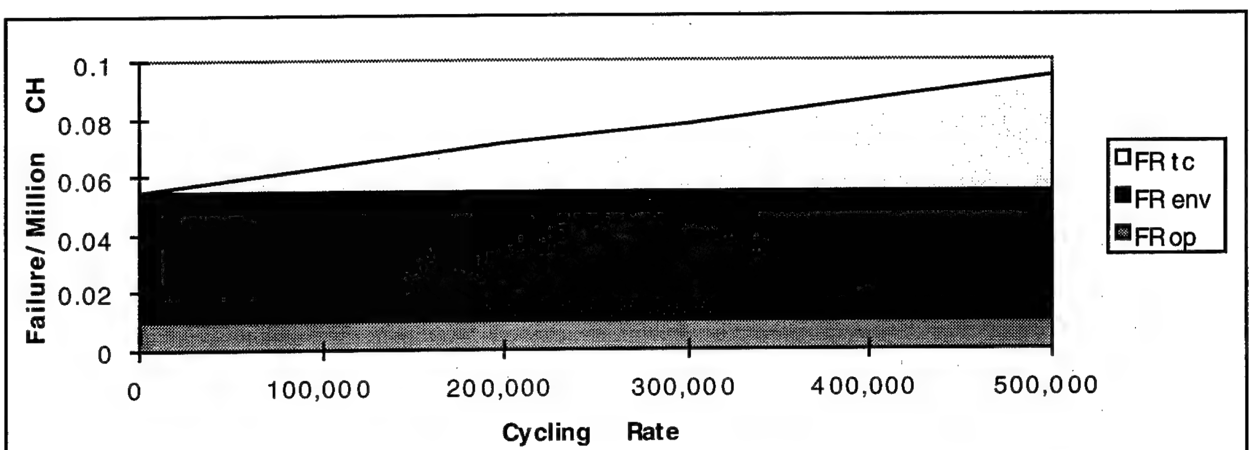

FIGURE 6.9-6: FAILURE RATE VS CYCLING RATE FOR SEVERE STRESSES

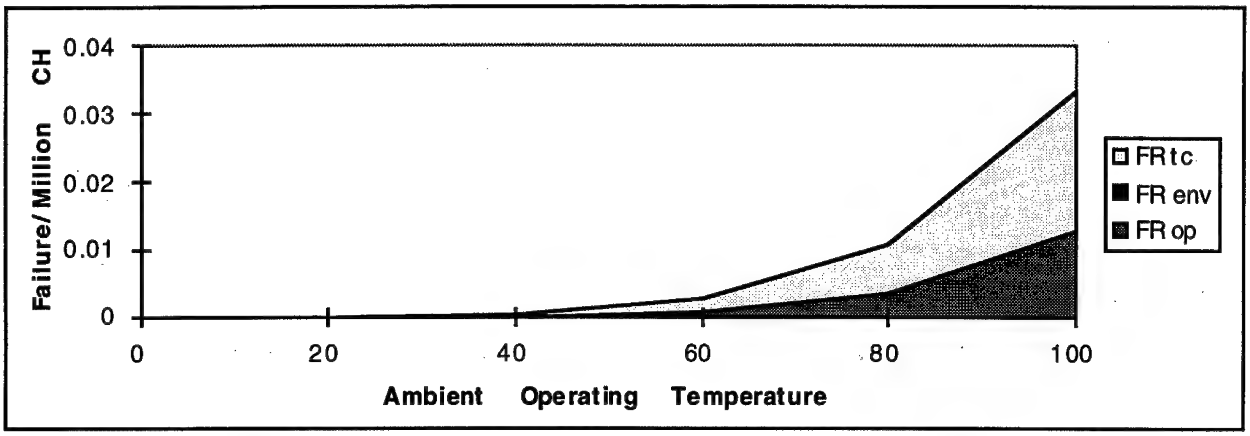

FIGURE 6.9-7: FAILURE RATE VS AMBIENT OPERATING TEMPERATURE FOR BENIGN STRESSES

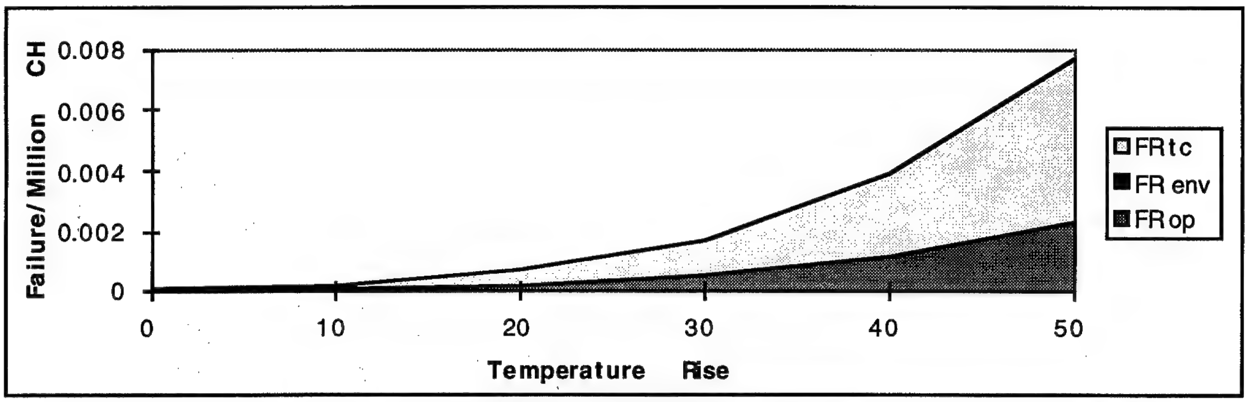

FIGURE 6.9-8: FAILURE RATE VS TEMPERATURE RISE FOR BENIGN STRESSES

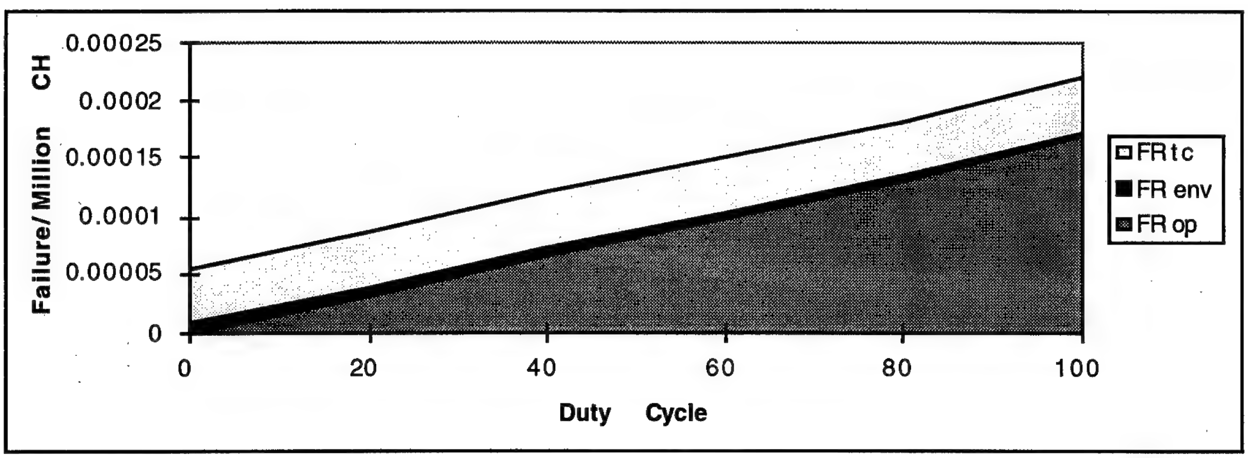

FIGURE 6.9-9: FAILURE RATE VS DUTY CYCLE FOR BENIGN STRESSES

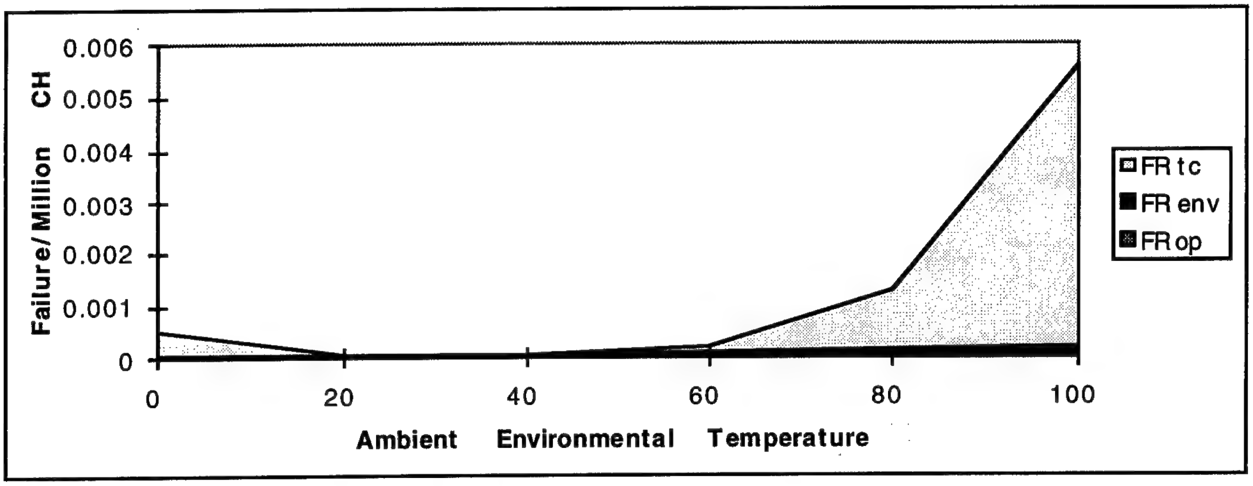

FIGURE 6.9-10: FAILURE RATE VS AMBIENT ENVIRONMENTAL TEMPERATURE FOR BENIGN STRESSES

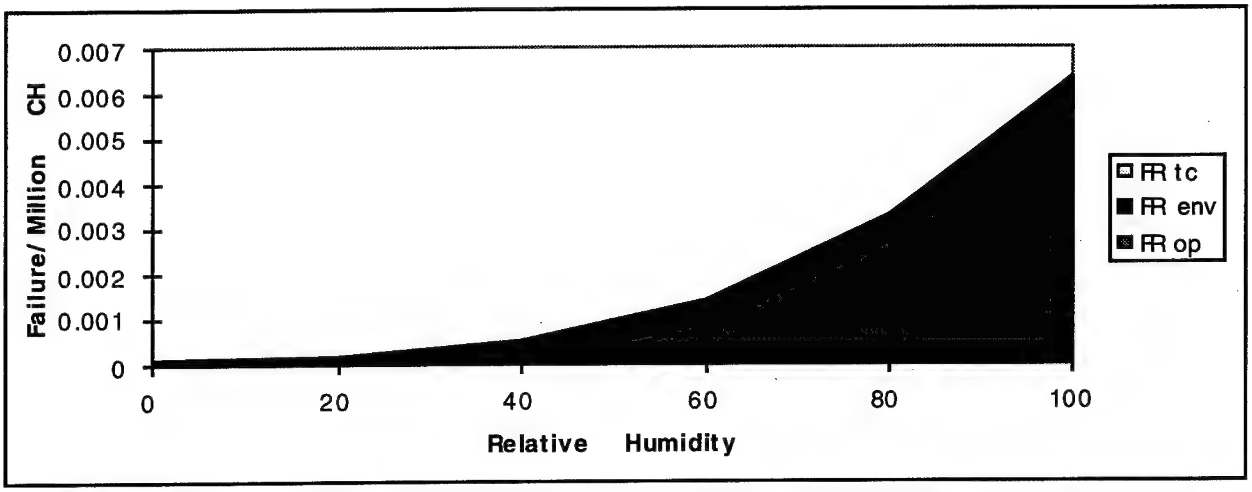

FIGURE 6.9-11: FAILURE RATE VS RELATIVE HUMIDITY FOR BENIGN STRESSES

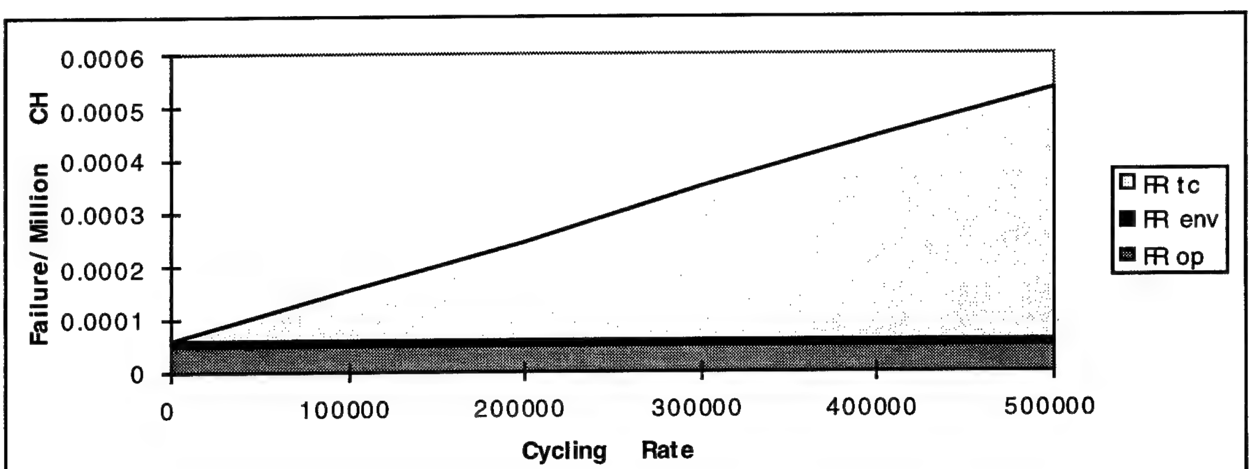

FIGURE 6.9-12: FAILURE RATE VS CYCLING RATE FOR BENIGN STRESSES

6.10 Model Assumptions and Limitations

With any model intended to describe stochastic processes, there are assumptions that need to be made due to the nature of the failure processes and uncertainties in the empirical data that is collected. Some of the assumptions used in development of the model are as follows:

1. The equipment in which the PEMs are operating is electrically stressed when the system is in operation and not stressed when the system is dormant.

2. The primary classes of failure mechanisms are a result of operational, temperature, humidity, and temperature cycling stresses.

3. The stresses applicable to the fielded applications from which the data was derived are a good approximation of the actual stresses.

4. The Arrhenious relationship adequately describes the failure rate acceleration as a function of temperature for failure mechanisms resulting from operational stresses.

5. The Peck model (Ref. 30) adequately describes the failure rate acceleration as a function of temperature and humidity.

6. The constant failure rate is appropriate for the first year of PEM operation.

There are also limitations of the model. Some of these are discussed in the following summary, which address several questions that may be asked when reviewing this model.

How Will The Prediction Results Compare To HAST Test Results?

Testing under HAST conditions primarily accelerates failure mechanisms that are a result of moisture intrusion. These mechanisms are accounted for in the model with the environmental failure rate term. Therefore, while HAST results are indicative of the robustness of a part for these mechanisms, it provides little indication of the robustness of the part when exposed to operating or temperature cycling stresses. The model has incorporated a means by which HAST test results can be used to provide a more accurate estimate for the environmental failure rate, but life test and temperature cycling test results are

needed to assess the robustness of the operational and temperature cycling failure rates.

How Do The Prediction Results Using This Model Compare With Predictions Performed Using MIL-HDBK-217?

The PEM model presented herein is inherently different than the models contained in MIL-HDBK-217. While the MIL-HDBK-217 model for microcircuits is based on qualitative environmental categories and generic quality categories, the PEM model is based on quantitative environmental stresses. Component quality is not explicitly accounted for but rather the model is representative of Best Commercial practices, since the data from which the model was developed was from companies with good part selection, application, and control processes in place. Significantly higher failure rates than those predicted can be realized if practices as good as those cited are not used.

Over What Time Period Is The Growth Factor Applicable?

Since the growth factors were derived from data in the 1980 to 1992 time period, the model is only valid over that period. Extrapolating beyond this range adds an additional degree of uncertainty in the resulting failure rate estimates. Extrapolating into the future assumes that the growth will continue at the same rate as it has over the time period that the data was collected. There are no guarantees it will continue, due to the nature of the reliability improvements in PEM technology. Some improvements have been revolutionary, while others have been evolutionary. The growth rates derived are an averaged result of both improvement types. Additionally, there tends to be quantum leaps in reliability as manufacturers identify, characterize, and design out life limiting failure mechanisms. Therefore, the failure mode distributions on which the model is based are not constant, but rather change in time as the technology evolves. Therefore, a prediction performed for the year 1992 which is used as the model baseline, will result in an assessment for which maximum confidence is attained, and extrapolating into future years will decrease this confidence.

What Is The Meaning And Relevance Of The Reliability Growth Factor?

The reliability growth factors (Π_G) discussed are, in reality, the observed reliability growth of the combined effects of the part design and manufacturing. The fact that the apparent growth rate is greater for field data than for life test data indicates that there is also a growth in non-component reliability factors from improved design and manufacturing practices. This is due to the fact that field reliability data typically accounts for all factors (component, design, and manufacturing) while life test results can only account for component related factors. Since life tests result predominantly in die related failures, another possibility is that package related reliability is growing at a faster rate than die reliability, thus accounting for the higher apparent growth rate from field data. Unfortunately, there was not adequate data to quantify the package (non-die) failure rate as a function of year (i.e., HAST data). If there were such data, it could be determined which effect is the likely cause of the difference in growth rates.

Why Isn't Device Complexity Accounted For?

There are several reasons for this. First, the effect on reliability of generic circuit functions has been quantified via the Π_{TYPE} factor. The available data did not support an analysis to further levels of details. Additionally, the failure rate attributable to the die typically contributes a small percentage to the overall failure rate and, therefore, accounting for die complexity would not have an appreciable impact on reliability. In the case of package complexity, as measured by size or number of pins, the available data did not reflect that it is a significant indicator of reliability, although this may be due to limitations in the data. However, in the case of both die and package, available data (i.e., life test, HAST) can be used to tailor the prediction, which will inherently account for device complexity.

Why Is The Failure Rate Unit Failures Per Million Calendar Hours?

A large percentage of PEM failures are the result of stresses that occur during nonoperating periods and the transition periods between operating and nonoperating status. Specifically, the anomalous reliability effects as a function of temperature and relative humidity act on the component during nonoperating

periods. Therefore, the only manner in which to account for both the operating and nonoperating periods is to predict the failure rate as a function of calendar hours. If the prediction results must be combined with predictions that are in failures per operating hour, an equivalent operating failure rate can be obtained by dividing the failure rate in failures per million calendar hours by the Duty Cycle (DC) to yield the failure rate in failures per million operating hours.

HAST Data Taken Above 130°C Is Known To Result In Failure Mechanisms That Are Not Typically Experienced In The Field. Why Was Data Above This Value Used In Development Of The Model?

While it is true that the failure mechanisms can change as a function of HAST temperature, HAST results are used in the model only to provide a basis for measurement by which the PEM can be evaluated. The model indicates that the average failure rate as a result of environmental stresses is .00046 failures per million calendar hours for a typical PEM whose mean life under 137°C, 85% RH HAST conditions is 1771 hours, and whose average stresses are 48°C ambient and 40% relative humidity. Use stresses more severe than 48°C, 40% RH will result in a higher predicted failure rate by the ratio equivalent to the Π_{RHT} factor. If the use temperature or relative humidity is greater than the average values to which the model is normalized, or if HAST testing (after correcting for the specific test stresses) results in a lower mean life than 1771 hours, the resulting predicted failure rate will be higher than .00046. Therefore, the implicit assumption by using HAST data above 130°C is that the Π_{RHT} acceleration factor is valid up to the HAST temperature. If there is reason to believe that the activation energy changes at high temperatures, then the model should be changed to reflect a more accurate value. However, since the activation energy used in the Π_{RHT} factor was based on the observed acceleration between 85°C/85% RH and HAST tests (much of which was above 130°C), the model should represent a reasonable failure rate approximation as a function of high temperature HAST data.

What Were The Dates Of The HAST Test Results To Which The Model Is Normalized?

The HAST tests analyzed were taken from a variety of sources, although the average test year was approximately 1992. Since this is also the year to which the

model is normalized, the model represents failure rates observed in 1992. HAST results would undoubtedly indicate growing reliability similar to the observed failure rates. For this reason, either the growth factor or HAST results should be used, but not both. Using both would account for the growth effect twice, resulting in unrealistically low failure rates.

6.11 Model Analysis

RAC used the following process to assess the relative importance of the terms in the model (i.e., the input parameters). First, the model was evaluated for all combinations of the eight factors identified in Table 6.11-1 using the values presented in the table. Thus a total of 19,683 modeled values were calculated.

TABLE 6.11-1: FACTORS, LEVELS, AND VALUES SELECTED

Factor	Number of Levels	Values
Device Type	3	Digital, Linear, Memory
Operating Temperature	3	0, 40, 80°C
Duty Cycle	3	10%, 50%, 90%
Relative Humidity	3	10%, 50%, 90%
Environmental Temp.	3	-25, 0, 25°C
Temperature Rise	3	0, 20, 40°C
Cycle Rate	3	100, 300, 500 thousand per million hours
Year	9	1980, 1982, 1984, ..., 1994, 1996

Summary statistics were then calculated. Table 6.11-2 illustrates the summary statistics for Device Type.

TABLE 6.11-2: SUMMARY STATISTICS FOR DEVICE TYPE

Device Type	Mean	Standard Deviation	N
All Devices	3.01	16.27	19683
Digital	1.74	7.32	6561
Memory	6.29	26.70	6561
Linear	1.00	3.37	6561

The analysis of variance (ANOVA) technique was used to assess the relative contribution of each of the eight factors. Results are shown in Table 6.11-3. The degrees of freedom column (df) is the number of levels minus one. The sum of squares column is the weighted sum of squared deviations of the level means around the grand mean. For example, from Table 6.11-2 for Device Type, the Sum

of Squares (SS) value of Table 6.11-3 is calculated as $6561 * [(1.74 - 3.01)^2 + (6.29 - 3.01)^2 + (1.00 - 3.01)^2] = [6561 * 16.41] = 107{,}839$. The Mean Square column represents the variance of the means and is calculated by SS/df. Finally, the Percent column (%) represents the percent of variance accounted for (i.e., due to) the factor. It is the ratio of the SS for the factor to the total SS. (Note: Since the data were generated from the model with no "residual" or "error" terms, the ANOVA technique provides an exact analysis. That is, the theoretical residual term is zero and any calculated residual is totally due to interaction terms not included in the model assessment).

TABLE 6.11-3: ANOVA RESULTS

Factor	df	Sum of Squares	Variance (Mean Sq)	%
Main Effects	22	987,730	44,897	18.95
Device Type	2	107,839	53,920	2.1
Operating Temp.	2	197,308	98,654	3.8
Duty Cycle	2	146	73	-
Relative Humidity	2	8	4	-
Environmental Temp.	2	79,685	39,843	1.5
Temp. Rise	2	53,628	26,814	1.0
Cycle Rate	2	47,069	23,535	0.9
Year	8	502,047	62,756	9.6
Residual	19660	4,223,256	215	-
Total	19682	5,210,985	265	-

The Year factor is the largest contributor, accounting for 9.6% of the total variation. However, all of the main effects together only account for about 19% of the total variation, leaving the remaining 81% unexplained. The reason(s) for this lack of fit is not intuitively obvious. Perhaps some of the ANOVA assumptions have been violated. For example, ANOVA assumes that the variation is "homogeneous". That is, for example, that the three Device Types have the same standard deviation. Looking back at Table 6.11-2, the three standard deviations are not equal. Another assumption is that the effects are linear. Since the model is exponential, that assumption is also violated. One way to account for the exponential nature of the model is by taking the natural logarithm of the failure rate and then re-analyzing the main effects. Results are shown in Table 6.11-4.

TABLE 6.11-4: ANOVA RESULTS USING LOG OF FAILURE RATE

Factor	df	Sum of Squares	Variance (Mean Sq)	%
Main Effects	22	210,418	9,564	91.3
Device Type	2	5,118	2,559	2.2
Operating Temp.	2	80,052	40,026	34.7
Duty Cycle	2	64	32	0
Relative Humidity	2	1,466	733	0.6
Environmental Temp.	2	16,608	8,304	7.2
Temp. Rise	2	11,949	5,974	2.6
Cycle Rate	2	4,764	2,382	2.1
Year	8	90,397	11,300	39.7
Residual	19660	19,988	1	-
Total	19682	230,405	11.7	-

Now the main effects account for over 91% of the total variation. Year is still the most important variable, as expected. Operating Temperature also accounts for a significant portion, with 34.7% of the variation due to the three levels of Operating Temperature selected. Environmental Temperature is a distant third with Temperature Rise, Device Type and Cycle Rate all contributing around 2%. Relative Humidity and Duty Cycle are unimportant factors.

The remaining 8.7% of the variation is due to interactions among the effects. To assess if Relative Humidity and Duty Cycle had a significant interactive effect, another ANOVA was performed. Results (not shown here) indicated that the Relative Humidity by Duty Cycle interaction accounted for about 0.6% of the total variation. Another ANOVA (results not shown here) looked at the contribution of the first and second order interactions. The first order (two-way) interactions (with 88 df) accounted for an additional 1.9% of the total variation. The second order (three-way) terms (with 244 df) accounted for an additional 1.8%. Thus, no major interaction terms accounted for a large percentage of the total variation.

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7.0 REFERENCES

1. Field Failure Return Data Texas Instruments, 1993.

2. Quearry, D., "Use of Plastic Components", NSWC Crane, SHARP Conference.

3. Kelley, Paul, "Plastic vs. Hermetic IC Analysis" Rockwell International, Collins Air Transport Division, November 9, 1993.

4. Source proprietary Temperature Cycling, Temperature/Humidity.

5. Olsson, C. "Reliability of Plastic Encapsulated Circuits", Ericsson Telecom.

6. Source Proprietary, Manufacturers Test Data.

7. Source Proprietary, Manufacturers Test Data.

8. Source Proprietary Incoming Component Quality Data.

9. Shen, D. Peterson, D. Sweet, J., "Plastic Packaging Availability Program" (BAA 92-02-MLK).

10. "Plastic Package Availability" R&D Status Reports #1 through #9, Contract DLA 900-92-C-1647, September 28, 1992 to August 2, 1993.

11. Goblish, B. E., Arno, R. G. and Nicolaides, R. V., "Reliability Study on Environmentally Protected Tape Automated Bonded Integrated Circuits".

12. Autoclave Data from component manufacturer.

13. Various Vendor Test Results.

14. Camilletti, R. C., "Reliability Without Hermeticity for Integrated Circuits Using Dow Corning's Ceramic Coating Technology", 1993 Advanced Microelectronics Qual/Reliability Workshop, August 24, 1994.

15. Commercial and Plastic Components in Military Applications Workshop (SHARP), Volume 2, 17, 18 November 1993.

16. Commercial and Plastic Components in Military Applications Workshop (SHARP), 17, 18 November 1993.

17. Chandra, G., "Low Temperature Ceramic Coatings For Environmental Protection of Integrated Circuits" Materials Research Society Proceedings, Vol. 203.

18. Plastic Packaging Availability, Six Month Review for the Tri Service Initiative, Contract DCA900-92-C-1647, May 26, 1993.

19. Rose, G. Virmani, N., "Fundamentals of Plastic Encapsulated Microcircuits (PEMs) For Space Applications", NASA Parts Project Office, March 3, 1994.

20. Gates, L. E., Steckler, B. E., "Environmental Performance of Sealed Chip-On-Board (SCOB) Memory Circuits", MCM Proceedings 1994.

21. Murphy, C.F., Kodnani, R. Peterson, D. W., "Evaluation of Non-Hermetic Coatings for MCM Applications through HAST, 85/85 and PCT." MCM Proceedings 1994.

22. McCullen, J.T., "Reliability of Electronic Packaging" Intel Corporation, SHARP Workshop, November, 1993.

23. Nishimura, A. Tatemichi, A., Miura, It., Sakamoto, T., "Life Estimation for IC Plastic Packages Under Temperature Cycling Based on Fracture Mechanics", 1987 Electronic Components Conference Proceedings, pp. 477-483.

24. "Reliability Considerations for Using Plastic Encapsulated Microcircuits in Military Applications", Harris Semiconductor, January 1994.

25. Current RL Activities in PEM Evaluation Rome Laboratory.

26. Lerose, S., Deleuze, G., and Brizoux, M., "Evaluation of Standard Plastic IC Reliability After Accelerated Sequential Testing" 7th International Conference on Reliability and Maintainability.

27. Machiels, F. Lijbers, G. Allaire, R., and Poiblaud, G., "Derating of Results According to Various Models and Prediction of Lifetimes of Plastic SMR's under Humidity Stress Conditions", Semiconductor, 5th International Conference": Quality In Electronic Components, 1991, Bordeaux, France.

28. "Reliability Without Hermeticity (RwoH) For Integrated Circuits (IC)," National Semiconductor, WL-TR-94-4086, March 1994.

29. Wahlstrom, A., "Plastic Components Study Phase III - Production and Test Qualifications," Technical Report TR-940199, Bofors.

30. Peck, D.S., "A Comprehensive Model for Humidity Testing Correlation", 1986 International Reliability Physics Symposium Proceedings, p. 44-50.

31. Gunn, J.E., R.E. Cumenga, "Rapid Assessment of the Humidity Dependence of IC Failure Modes by Use of HAST", International Reliability Physics Symposium Proceedings 1983, p. 66.

7.1 Supplemental References

32. EIA A-112: Moisture-Induced Stress Sensitivity for Plastic Surface Mount Devices, EIA/JEDEC JC 14.1, 1993- Draft (Council Ballot).

33. EIA A-113: Preconditioning of Plastic Surface Mount Devices Prior to Reliability Testing, EIA/JEDEC JC 14.1, 1993- Draft, (In Committee).

34. IPC TM 650 Method 2.6.20 (In Committee) Plastic Package Cracking Evaluation Method.., Revision A.

35. IPC TM 650 Method 2.6.22 (In Committee) Acoustic Microscopy.

36. Use of Microfocus X-Ray Radiography and High-Frequency Ultrasonics to Evaluate Plastic-Packaged ICs. Wevers, Martine, (Katholieke Universiteit Leuven, Belgium), Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX, Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

37. High Frequency Acoustic Imaging of Advanced Materials. Arnold, W., (Frauenhofer-Institut fur zerstorungsfreie Purfverfahren, Germany, Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX, Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

38. Moisture Sensitivity of Plastic Surface Mount Devices, Shook, R.L., (AT&T Bell Labs, USA). Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX, Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

39. Applications of Acoustic Microscopy to Failure Analysis of Semiconductor Devices, Glacet, Jean-Yves, (Motorola, France). Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX, Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

40. Evaluation of Die Attach using SAM, Pfannschmidt, B., (Siemens, Germany). Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX, Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

41. Solder Joint Inspection. Minet, J., (Hewlett Packard, France). Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in

Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX, Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

42. Non-Destructive Metrology of Plastic Package Internal Features, Ottoboni, S., (Hewlett Packard, France). Proceedings, Seminar and Workshop, Evaluation of Methods for Detecting Discontinuities in Plastic-Packaged Integrated Circuits Using Acoustic Microscopy, February 1993, Diepenbeek, Belgium. SONIX Inc. Hosted by the Training Division of the Institute of Materials Research, Limburgs Universitair Centrum, Belgium.

43. Thermal Stress and Strain in Microelectronics Packaging, Lau, John H., (Hewlett Packard, Palo Alto, CA). Van Nostrand Reinhold, 1993. ISBN 0-442-01058-3 Particularly, Chapter 13, and 7, 10, 11, 12, 14, 23.

44. Characterization of Integrated Circuit Packaging Materials. Moore, T.M., (TI) and McKenna, R.G. (Ex- TI, Compaq), Butterworth-Heinemann, 1993. ISBN 0-7506-9267-7.

45. IPC SM 786 Draft 7, August 1993.

46. Moisture Sensitivity Characterization of Plastic Surface Mount Devices Using Scanning Acoustic Microscopy, Shook, R.L., (AT&T Bell Laboratories, Allentown, PA). Proceedings, 1992 IRPS, pp. 157-168.

47. The Impact of Delamination of Stress-Induced and Contamination Related Failure in Surface Mount ICs, Moore, T.M., and Kellsall, S.J., (Texas Instruments, Dallas, TX). Proceedings, 1992 IRPS, pp. 169-176.

48. Comparison of Delamination Effects Between Temperature Cycling Test and Highly Accelerated Stress Test in Plastic Packaged Devices, van Gestel, R., de Zeeuw, K., (Delft University of Technology, the Netherlands), van Gemert, L., and Bagerman, E., (Philips Semiconductor, The Netherlands), Proceedings, 1992 IRPS, pp. 177-181.

49. X-Ray Analysis of Package Cracking During Reflow Soldering, Harada, M., Tanigawa, S., Ohizumi, S., and Ikemura, K., (Nitto Denko Corporation, Japan), Proceedings, 1992 IRPS, pp. 182-189.

50. New Thin Plastic Package Crack Mechanism Induced by Hot IC Die Marks, M.R., (AMD, Singapore), Proceedings, 1992 IRPS, pp. 190-197.

51. Acoustic Evaluation of Electronic Plastic Packages, Siettmann, J., Dias, R., and Fiebelkorn, K., (Intel/Chandler, AZ), Proceedings, 1992 IRPS, pp. 309-314.

52. Improving Plastic Package Reliability, Topic 2, Moore, T.M., Kelsall, S.J., and Edwards, D.R., (Texas Instruments), Tutorial Notes, 1992 IRPS, pp. Topic 2 - 2d17.

53. Mechanical Performance of Thin Plastic Packages, Kiang, B.H., and Jahsman, W.E., (Intel/Chandler, AZ), ASME AMD-Vol. 131/EEP - Vol. 1, pp. 115-124.

54. Stress Measurement in Microelectronic Packages Subjected to High Temperatures, Suhling, J.C., Carey, M.T., Johnson, R.W., and Jaeger, R.C., (Auburn University, Auburn, Alabama), ASME AMD-Vol. 131/EEP - Vol. 1, pp. 143-152.

55. Corrosion Modeling in Microelectronic Devices, Shan, X., Pecht, M., and Christou, A., (CALCE, University of Maryland, College Park, MD), Transactions, Microcircuits and Electronic Packaging, ISHM, Volume 15, No. 1, First Quarter, 1992, pp. 1-10.

56. On Lead Finger Designs in Plastic Packages for Enhanced Pull Strength, Nguyen, L.T., (National Semiconductor, Santa Clara, CA), Transactions, Microcircuits and Electronic Packaging, ISHM, Volume 15, No. 1, First Quarter, 1992, pp. 11-33.

57. A Surface Acoustic Wave Sensor for Measuring Relative Adhesion and Surface Properties of Polyimide Films, Galipeau, D.W., Veteline, J.E., (Laboratory for Surface Science and Technology, Department of Electrical Engineering, University of Maine, Orono, ME) and Feger, C., (IBM, T.J. Watson Research Center), Transactions, Microcircuits and Electronic Packaging, ISHM, Volume 15, No. 1, First Quarter, 1992, pp. 53-60.

58. Destruction of Metal-Resin Adhesion Due to Water Penetrating Through the Resin, Ohno, H., Endo, K., Araki, Y., (Department of Dental Materials Science, School of Dentistry, Higashi-Nippon-Gakuen University), Ishikari-Tobetsu, Hokkaido, Japan), Asakura, S., (Division of Materials Science and Chemical Engineering, Faculty of Engineering, Yokohama National University, Yokohama, Kanagawa, Japan), Journal of Materials Science Vol. 27, No. 19, (1992) pp. 5149-5153.

59. Application of Multiple Failure Analysis Techniques to Resolve Moisture Related DRAM Failures, M.J. Shirle and P.E. Miller (TI, Dallas, Texas), W. Tan (TI, Singapore), D. Corum (TI, Stafford, TX). Proceedings, ISTFA '92, Los Angeles, CA, 17-23 October 1992, pp. 125-134.

60. Acoustic Microscopy (A.M.) Applications, R.A. Carbone (Hewlett Packard Company, Roseville, CA), Proceedings, ISTFA '92, Los Angeles, CA, 17-23 October 1992, pp. 301-306.

61. Evaluation of Aluminum Wirebonding in Discrete Transistors Using Scanning Acoustic Microscopy (C-SAM), E.J. Crawford (IBM Procured Technologies International, East Fishkill, NY), Proceedings, ISTFA '92, Los Angeles, CA, 17-23 October 1992, pp. 307-314.

62. C-AM Analysis of Plastic Packages to Resolve Bonding Failure Mode Miscorrelations, R. Angeles, G. Ilog and J. Nicolas (TI, Baguio City, Phillipines), T.M. Moore (TI Dallas, TX), K.S. Wills (TI, Houston, TX), Proceedings, ISTFA '92, Los Angeles, CA, 17-23 October 1992, pp. 315-320.

63. PGA Failure Analysis Using Acoustic Microscopy and a Novel Sample Preparation Technique, R. St. Amand and J. Ide (DEC, Northboro, Massachusetts), Proceedings, ISTFA '92, Los Angeles, CA, 17-23 October 1992, pp. 321-328.

64. Evaluation of Methods for Delamination Detection by Acoustic Microscopy in Plastic-Packaged Integrated Circuits, Van Doorselaer, K., (Alcatel Bell, Antwerpen, Belgium), Moore, T.M., (Texas Instruments, Dallas, TX), Tiziani, R., (SGS-Thomson Microelectronics, Brianza, Italy), Baelde, W., (Philips Semiconductors, The Netherlands), Proceedings, ISTFA '92, Los Angeles, CA, 17-23 October 1992, pp. 425-431.

65. C-Mode Acoustic Microscopy Applied to Integrated Circuit Package Inspection, Moore, T.M., (Texas Instruments, Dallas, TX), Solid State Electronics, 1992, Volume 35, No. 3, pp. 411-421.

8.0 SUMMARY AND CONCLUSIONS

The major package-related failure mechanisms of both plastic and hermetic integrated circuits, derived from field failure returns and life test results, are summarized in Table 8.0-1. While most are common to both types of devices, it is important to note that each package type does exhibit unique mechanisms. Specifically, hermetic packages exhibit greater susceptibility to mechanical stresses. Plastic packages, on the other hand, due to their solid molded construction, are essentially immune to this mechanism. Consequently, tests such as impact shock, centrifuge and vibration, which are designed to mechanically stress the device, are not typically specified in the qualification of PEMs. The failure mechanisms which appear to be unique to plastic devices are (1) moisture ingress, (2) SMD package cracking, and (3) metal deformation/cracked passivation (i.e., delamination).

TABLE 8.0-1: PLASTIC AND HERMETIC IC PACKAGE-RELATED FAILURE MECHANISMS

Description	Stress/ Source	Response	Accelerating Test	Plastic	Hermetic
Cracked Die	Thermal	Electrical Short/Open	Temperature Cycle	X	X
	Mechanical	Electrical Short/Open	Impact Shock		X
Wire Breaks	Thermal	Electrical Open	Temperature Cycle	X	X
	Mechanical	Electrical Open	Vibration, Centrifuge		X
Wire Lifts	Thermal	Electrical Open	Temperature Cycle	X	X
	Mechanical	Electrical Open	Vibration, Centrifuge		X
Wire Lifts (Intermetallic)	Thermal	Electrical Open	High Temperature Storage	X	X
Cracked Package Seals	Thermal	Loss of Hermeticity	Temperature Cycle		X
	Mechanical	Loss of Hermeticity	Impact Shock		X
Corroded Seals, External (Pin-to-Pin Shorts)	Moisture	Loss of Hermeticity	Humidity, Salt Atmosphere		X
Interface Delamination	Thermal	Reduced Moisture Resistance	Temperature Cycle	X	
Internal Water Vapor	Package Assembly	Aluminum Corrosion	Low Temperature Bias Life		X
Moisture Ingress	Moisture	Aluminum Corrosion	Temperature/Humidity/ Bias, Autoclave, HAST	X	
SMD Cracked Package (Popcorn Effect)	Thermal	Reduced Moisture Resistance/Elect. Open	Humidity/Solder Shock Sequence	X	
Metal Deformation/ Cracked Passivation	Thermal	Electrical Short/Open	Temperature Cycle	X	
Lifted Die	Thermal Mechanical	Electrical Short/Open, Thermal Degradation	Temperature Cycle, Impact Shock, Centrifuge		X
Die Attach Voids	Package Assembly	Thermal Dissipation, Low D/A Strength, Cracked Die	Bias Life, Temperature Cycle, Centrifuge	X	X
Loose Die Attach, Sealing Materials, and Particles	Package Assembly	Electrical Short	Vibration/Shock PIND		X

The ingress of moisture and contaminants, which occurs primarily through the package plastic-to-leadframe interface, can result in the eventual electrolytic corrosion of effected aluminum metallization, usually manifested in an open circuit failure mode. The rate at which this corrosion occurs is a direct function of the applied bias voltage, the amount of moisture present, the chip operating temperature, and conductivity of the penetrating electrolyte. As indicated in the table, this mechanism is accelerated by Temperature-Humidity-Bias (THB), HAST and autoclave tests. Improvement trends in process cleanliness, passivation integrity, mold compound adhesion and leadframe construction will help minimize the likelihood of this mechanism manifesting during field use. An additional important factor is the elimination of sources of halides and other highly ionic materials during circuit board assembly.

SMD packages are particularly susceptible to package cracking during board assembly solder reflow operations such as vapor phase, IR and wave solder. The cracking results from the sudden vaporization of absorbed moisture within the bulk plastic. The resultant cracks provide a path for the infiltration of moisture and contaminants onto the die surface. Reliability will ultimately be affected via failure modes that result in immediate electrical rejects, intermittent contacts, or degrading performance over the long term. Shear stresses directly resulting from the package cracks can cause bond wires to lift and/or break, particularly at the die corners. This "popcorn" phenomena has proven to be a function of solder temperature conditions; package dimensions and moisture content; and mold compound adhesion. The effects are most dramatic on large, high pin count packages. Preventive measures include a dehydration bake, followed by shipment in dry-pack containers. Industry research continues in attempts to develop molding compounds which are mechanically robust under these conditions.

Under temperature cycling conditions, shear stresses occur between the molding compound and die surface interface, due primarily to their different TCE characteristics. These stresses, while negligible at the die center, increase exponentially out to the die corners and edges. Larger die, therefore, are more prone to this failure mechanism. Under extreme conditions, the stresses may become so severe that surface passivation and interlevel oxides can crack, and metallization lines can deform or break. These effects have been particularly noted on large die with wide metallization runs at the die surface extremities. This failure mechanism

can be minimized through improved metallization layout rules, more planarized die surfaces, the use of die coatings, and low stress mold compounds. Depending on the package style, the device user may be required to strictly control the operational temperature cycle extremes.

Data has been presented that represents reliability levels of PEMs in field use and when exposed to various testing conditions. The distributions presented represent industry average lifetimes and the field data represents industry average failure rates. From this data, wide variations were observed as a function of the specific processes used to manufacture the component. While large variations are observed for most component types, the difference is especially pronounced for PEMs. This observation makes component and vendor selection activities a critical element if high reliability levels are to be achieved.

The reliability of PEMs has increased orders of magnitude over the last fifteen years. The average rates at which this growth has been occurring was summarized previously for various device and test types. This improvement has been a result of the maturing of PEM technology and the added attention given to PEMs by manufacturers as a result of their increased utilization rate. Additionally, there has been much learned in the selection and application of PEMs, as can be seen from the acceptance of various specifications from the Military (MIL-I-38535), JEDEC (Standard 26), and the Automotive Electronics Council (CDF-AEL-Q100).

From the data analysis and model development performed in this effort, several conclusions can be made. It is evident that PEMs have the potential to be highly reliable in their early life when used in benign applications. It is also evident, however, that their reliability is a strong function of the application stresses. This can be seen by the difference in reliability between the benign and severe stress environments for which there was field data. There was no reason to believe that the differences were due to the specific part selection, procurement practices or screening, of any of the data sources, since they all represented what RAC would consider best commercial practices based on sound part selection, application and control principals.

The data collected indicates that the primary failure modes of PEMs are a result of environmental stresses and temperature/power cycling. Under typical field

use conditions, the portion of the failure rate attributable to the active silicon element appears to be very small compared to the package related failure mechanisms. This, however, is not the case for high temperature life tests, in which the active silicon element comprises approximately 72% of the overall failure rate. Since the failure rate for life tests is higher than for ground benign field operation, and temperature is the primary stress distinguishing ground benign field and life tests, the conclusion that can be made is that temperature is indeed a significant failure rate acceleration factor for die related failures.

A failure rate prediction model has also been developed that allows relatively accurate assessments of PEM failure rates in a wide variety of applications. Several features of this model have been presented. Highlights of these features include:

1. The ability to tailor the prediction in the event empirical test data is available. If it is not available, then the prediction reverts to the industry average failure rates.

2. Separate quantification of the failure rates associated with operational, environmental, and temperature cycling stresses. This results in a flexible model capable of predicting the reliability in almost any conceivable application scenario, from storage to continuous operation.

However, when PEM attributes are discussed, it becomes obvious two camps exist, Pro-Plastic and Conservatives, as illustrated in Figure 8.0-1.

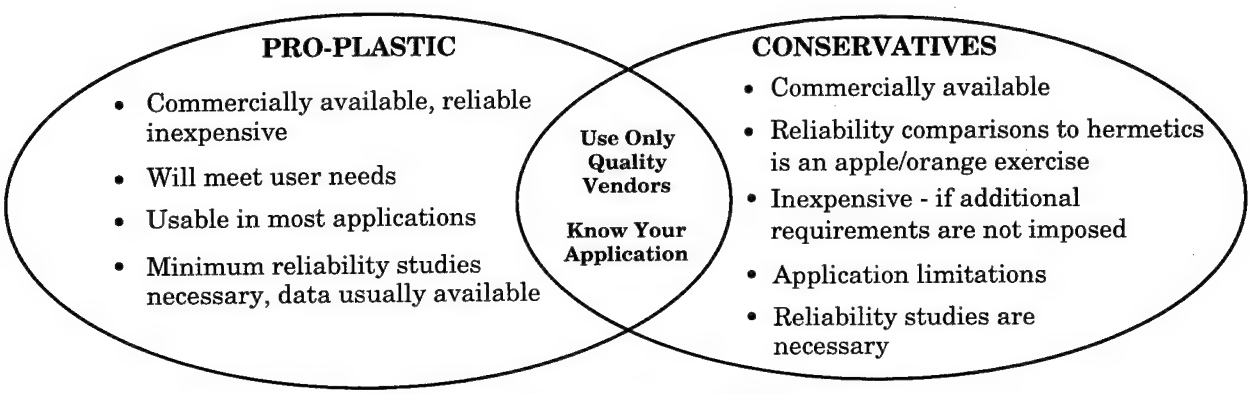

FIGURE 8.0-1: PEM ATTRIBUTES

In the "Pro Plastic" camp the proponent for using plastic encapsulated microcircuits (PEMs) states that they are widely available and are as reliable as ceramic

parts or maybe even more reliable because of the high volumes of these devices being produced. Furthermore, they can be 30% to 50% cheaper than a military MIL-STD-883 compliant ceramic device. Use of PEMS are capable of meeting user needs and applications within minimal or no added testing required and finally there has been extensive reliability studies justifying their endorsement of PEMS.

On the "conservative" side, the individual or organization will agree that PEMS are widely available, however they are only inexpensive if no additional testing requirements are necessary (i.e., electrical testing at -55°C to 125°C versus commercial guaranteed operation environment at 0°C to 70°C). Reliability comparisons are flawed and in many cases are apple/orange exercises with testing and failure definitions different between both categories of product. The "conservative" believes there may be application limitations, but is unsure because they are not satisfied with the reliability test results to date. Based on this they feel that additional reliability studies need to be conducted before they will recommend their use for specific applications.

Both agree that you should use PEMs from quality vendors and you should understand their application and use environments.

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Appendix A:

List of Acronyms

List Of Acronyms

AFB	Air Force Base
AMC	Army Material Command
AOQ	Average Outgoing Quality
ARL	Army Research Lab
ARPA	Advanced Research Programs Agency
ATC	Accelerated Thermal Cycling
BCIS	Battlefield Combat Identification System
BCP	Best Commercial Practice
BCP&P	Best Commercial Parts & Practices
CECOM	U.S. Army Communications-Electronics Command
CERDIP	Ceramic DIP
CMI	Continuous Manufacturing Improvement
CMOS	Complementary Metal Oxide Semiconductor
CNI	Communications, Navigation & Identification
CSAM	C-Mode Scanning Acoustic Microscope
DESC	Defense Electronic Supply Center
DLA	Defense Logistics Agency
DMPG	Defense Microcircuit Planning Group
DoD	Department of Defense
DPA	Destructive Physical Analysis
DTIC	Defense Technical Information Center
EIA	Electronics Industry Association
EIAJ	Electronics Industry Association of Japan
EMC	Epoxy Molding Compound
EPEQ	Equivalent Plastic Strain
ESC	Electronics System Center
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
GPS	Global Positioning System
HAST	Highly Accelerated Stress Test
IC	Integrated Circuit
ICWG	Industry Coordinating Working Group
IMPACT	Information Management Program on Advanced Component Technologies
ISO	International Standards Organization
JEDEC	Joint Electronic Device Engineering Council
JQA	Joint Qualification Alliance
JTIDS	Joint Tactical Information Distribution System
LTPD	Lot Tolerance Percent Defective
MCM	Multichip Module
MOD	Ministry of Defense (French)
MPCAG	Military Parts Control Advisory Group
MSE	Mobile Subscriber Equipment
MTTF	Mean Time To Failure
NASA	National Aeronautics and Space Administration
NDI	Non-Developmental Item
NSWC	Naval Surface Warfare Center
OEIC	Optoelectronic Integrated Circuit

List Of Acronyms (Cont'd)

OEM	Original Equipment Manufacturer
OSD	Office of Secretary of Defense
PCB	Printed Circuit Board
PCP	Plastic Component Program
PDIP	Plastic Dual In-Line Package
PED	Plastic Encapsulated Devices
PEM	Plastic Encapsulated Microcircuit
PLGR	Precision Lightweight GPS Receiver
PQFP	Plastic Quad Flat Package
PTSC	Photonics Technology Support Center
PWB	Printed Wiring Board
QCI	Quality Conformance Inspection
QFP	Quad Flat Package
QML	Qualified Manufacturing List
QPL	Qualified Parts List
RAC	Reliability Analysis Center
RAM	Random Access Memory
RH	Relative Humidity
RL	Rome Laboratory
RwoH	Reliability Without Hermeticity
SCOB	Sealed Chip On Board
SHARP	Standard Hardware Acquisition and Reliability Program
SINCGARS	Single Channel Ground and Airborne Radio System
SMD	Standard Military Drawing
SMD	Surface Mount Device
SMT	Surface Mount Technology
SOIC	Small Outline Integrated Circuit
SPC	Statistical Process Control
SPO	System Program Office
TAB	Tape Automated Bonding
TCE	Thermal Coefficient of Expansion
TQM	Total Quality Management
TSOP	Thin Small Outline Package
UHF	Ultra High Frequency

Appendix B:

Plastic Encapsulated Microcircuit Conferences

APPENDIX B-1: SECOND ANNUAL SHARP COMMERCIAL AND PLASTIC COMPONENTS IN MILITARY APPLICATIONS WORKSHOP

Presentation Title	Presenter	Affiliation
Reliability Issues with Commercial and Plastic Packaged Microcircuits for DoD Applications	James Reilly	Rome Laboratory (RL)
Certification/Qualification for MIL-I-38535 (QML)	Mike Adams	Defense Electronic Systems Command (DESC)
Plastic IC Field Failure Returns	Jack Farrell	Reliability Analysis Center (RAC)
Plastic Packaging in Japan	Dr. Michael Pecht	University of Maryland
Accelerated Testing of Plastic ICs	Dan Quearry Leon Glaze	Naval Surface Warfare Center (NSWC)
Reliability Without Hermeticity (RwoH)	Rob Camilletti	Dow Corning
Plastic Packaging Availability Program	John Jackson	National Semiconductor
Molding Compound Technology for Military Applications	Bill Bates	Plaskon
Plastic Package Overview and Reliability	J.T. McCullen	Intel
Plastic Part Usage in Commercial Avionics	John Fink	Honeywell
High Volume Plastic IC Users Perspective	Doug Quinn	IBM
Where Are The Costs? Is That The Issue?	Joe Neel	Motorola
Issues to be Understood & Resolved as Military Moves to Plastics	Buf Slay	Texas Instruments
Usage of High Reliability PEMs in Military Avionics	Mark Cooper	Litton
A Proposed Flow for DPA of Plastic Encapsulated IC's	Todd Castello	Oneida Research Services

APPENDIX B-2: THIRD ANNUAL SHARP COMMERCIAL AND PLASTIC COMPONENTS IN MILITARY APPLICATIONS WORKSHOP

Presentation Title	Presenter	Affiliation
Not All Commercial Integrated Circuits May Be Upgradeable To Military Or Avionics Environments	Dr. Bob Byrne	National Semiconductor
Commercial and Industrial (IC) Components in Military Applications	Bill Ricci	Magnavox
Delco Approach to PEM Failure Rate Determination	Richard Mosbarger	Delco Electronics
Selecting The Right Supplier: The Key to Successfully Implementing A Commercial Parts Program	Gary Foisy	Motorola
Popcorning in Plastic Encapsulated Microcircuits	Dr. Mike Pecht	University of Maryland
Reliability Considerations For Using Plastic Encapsulated Microcircuits in Military Applications	William Shultz	Harris
Automotive Electronics Council	Gerald Servais	Delco
Why QML Is Best Commercial Practice	Buf Slay	Texas Instruments
The First MIL-I-38535 Plastic Packaging Technology Validation	Andy Thacker	DESC
Technology Issues for Using Commercial ICs	Tom Shaw	Institute for Defense Analysis
The Use of Commercial Components in ELDEC Avionic & Military Power Supply Products Components in Military Power Supplies	John Ardussi	ELDEC
Plastic Encapsulated Microcircuits Cannot Be Used In All Military Applications	Dr. Noel Donlin	US Army Missile Command
DLA Plastic Packaging Availability (PPA) Program 6 Month Review PPA Program Overview Reliability without Hermeticity (RwoH) Sensor Chip Development	 Bob Tonar Ron Kovacs Rob Camilletti Dave Peterson	 DLA National Semiconductor Dow Corning Sandia Labs
Molding Compound Technology for Military Applications	Nick Rounds	Plaskon
Plastic Part Usage in Commercial Avionics	Fred Malver John Fink Bruce Johnson	Honeywell CFS

APPENDIX B-3: 1993 ADVANCED MICROELECTRONICS QUALIFICATION/RELIABILITY WORKSHOP

Presentation Title	Presenter	Affiliation
883B Ceramic I.Cs vs. Plastic I.Cs for Commercial Aircraft	John Fink	Honeywell
Usage of High Reliability Plastic Encapsulated Microcircuits in Military Avionics Applications	Mark Cooper	Litton
Iridium^{TM} Parts Program: An Innovative Application of Best Commercial Parts & Practices to a Satellite-Based Cellular Communications System	Gary Foisy	Motorola
Best Commercial Practices - Supply Based Management	Eugene Hnatek	Tandem Computers
Guidelines for Standardization of Plastic-Encapsulated Devices in Military Applications	L.T. Nguyen/ J.A. Jackson	National Semiconductor
The Development of an Industry Standard Stress Test Driven Qualification	Robert Knoell/ Nick Lycoudes	Ford/Motorola
Reliability Without Hermeticity (RwoH) for Integrated Circuits	Robert Camilletti	Dow Corning
Adopting Best Commercial Practices for DoD Microcircuits	Mark Gorniak/ Joseph Dupay	Rome Laboratory/DESC
The Qualified Manufacturers List (QML) MIL-I-38535 Program Update	Jim Blanton	DESC
F-22 Electronic Parts Cost Reduction Initiatives	Gary Koehler	Lockheed
Independent Verification of QML Parts Quality for Space Applications	Capt. Mark MacDonald	Phillips Laboratory
DoD Microcircuit Application Handbook	Patrick Layden	Army Research Laboratory
QPL-QML Conversion and Maintaining a Viable IC Supplier Base for DoD	T.S. Edwards	National Semiconductor

APPENDIX B-4: 1994 ADVANCED MICROELECTRONICS QUALIFICATION/RELIABILITY WORKSHOP

Presentation Title	Presenter	Affiliation
Component Reliability Behavior and Environmental Analysis of Equipment Operated In Tropical Climate Conditions	Dr. Nihal Sinnadurai	Middlesex University
Improve Military System Reliability By Using Commercially Manufactured Microelectronic Parts	Wisty Olsson	Electronic Systems Advanced Technology, Inc.
Development of a GaAs MMIC Plastic Encapsulated Microcircuit (PEM) for High Volume Munitions Applications	N. Hildreth M. Shifrin B. Bedard	Hittite Microwave Corp.
Plastic Encapsulated Microcircuits Cannot Be Used In All Military Applications	Dr. Noel E. Donlin	US Army Missile Command
Why QML Is Best Commercial Practice	Buf Slay	Texas Instruments, Inc.
Microelectronic Part Grade Selection Based On Military Applications	John M. Hartman	Analog Devices, Inc.
Non-Military Parts Application Initiatives	Eric M. Pfeifer J. Michael Ryskamp	US Army Communication-Electronics Command
In-Service The Right Supplier: The Key to Successfully Implementing A Commercial Parts Program	Gary Foisy	Motorola, Inc.
Reliability Considerations For Using Plastic-Encapsulated Microcircuits In Military Applications	William L. Schultz Sheldon Gottesfeld	Harris Semiconductor
Approach to Demonstrate Plastic Encapsulated Microcircuit Reliability for Missile Applications	Sun Man Tam	Texas Instruments
P3I Using Commercial Plastic ICs	Ed Kross	DSD Laboratories
Commercial and Industrial Components In Military Applications	Bill Ricci	Magnavox Electronic Systems Company
Best Commercial Practice Parts as Applied on the AN/PSN-11 PLGR	Douglas A. Emerson	Rockwell International
The Use of Plastic Encapsulated Microcircuits	Michael LoDebole	ITT Aerospace
The GDLS Approach to BCP Components Use In Military Programs	Katrina Fay	General Dynamics Land Systems
The First MIL-I-38535 Plastic Packaging Technology Validation	James E. Blanton Michael Adams Andrew Thacker	DESC
Quality and Reliability of Plastic Encapsulated Modules (PEMS)	Nick Lycoudes	Motorola, Inc.
Commercial Plastic ICs in Military Applications	Dan Quearry	Naval Surface Warfare Center

APPENDIX B-5: 1995 ADVANCED MICROELECTRONICS QUALIFICATION/RELIABILITY WORKSHOP

Presentation Title	Presenter	Affiliation
In-Service Reliability of Ceramic 883B Integrated Circuits	J.W. Fink	Honeywell
Plastic Encapsulated Microcircuit (PEM) Reliability and Cost Effectiveness Study	D.A. Emerson	Rockwell International
Civil Engine Control Reliability - The Challenge for Plastic Encapsulation	Dr. R.M. Newman C. Hughes	Lucas Electronics
Military Products From Commercial Lines	P.M. Vicent M. Kinsella	Wright Patterson, AFB
ITT's Commercial Parts Program Plan	C. Ulliman E. Jacoby	ITT Aerospace
SINCGARS BCP--The Next Generation	F. Fernandez R. Kempton F. Smith	General Dynamics
Assessment Methodology for the Transition to Commercial Components for Defense Applications	M.M. Barre	MATRA Defense
MIL-HDBK-179A: A DoD Microcircuit Acquisition Guide	P.J. Layden	U.S. Army Research Laboratory, Fort Monmouth, NJ
Plastic Encapsulated Microcircuits (PEMs) Commercial/Industrial Qualification Approaches	N. Lycoudes	Motorola, Inc.
Statistical Bin Limits for Improved Product Quality	R. Verma	Intel Corporation
Reducing Systems Maintenance Costs by Component Standardization (Reducing Obsolescence Cost and More)	K. Segal	Advanced Technologies in Electronics Users Association
Product Average Testing For a Better Out-Going Product Quality Monitor	D.Y. Klosterman	Intel Corporation
New Testing Techniques for Semiconductor Devices	E. Weis G. Chanoch S. Snyder G. Zvoolon	E.D.E. Electronics Ltd. National Semiconductor Inc. Tadiran IDF
Thermal and Electrical Operation and Malfunction of Electronics Detected and Imaged by Means of Low Cost Liquid Crystal Sensing	Dr. N. Sinnadurai	TWI
Moisture and Stress Test Chips for Plastic Packaging Qualification	L. Nguyen R. Kovacs	National Semiconductor Corp.
HAST and THB Moisture Testing: A Status Report	T. Maudie N. Lycoudes	Motorola, Inc.
SPECRITE, A DoD Acquisition Reform Tool	S. Gilstrap G. Thomas	NSWC Crane Division
Long Term Storage Reliability of Plastic Encapsulated Microcircuits	A.K. Fowler F.P. McCluskey	CALCE, University of Maryland
Best Commercial Practice in Military Semiconductors	B. Slay	Texas Instruments Inc.

APPENDIX B-5: 1995 ADVANCED MICROELECTRONICS QUALIFICATION/RELIABILITY WORKSHOP (CONT'D)

Presentation Title	Presenter	Affiliation
Control of Popcorning By Using Optimized Process Conditions	R. Gannamani R. Munamarty F.P. McCluskey	CALCE, University of Maryland
An Evaluation of Acoustic Microscopy (For Non-Destructive Inspection of PEMs, MCMs etc.)	A.W. Hawes	NSWC Crane
Scanning Acoustic Microscope and Dye Penetrant Evaluation of Plastic Encapsulated Microcircuits (PEM)	A.S. Chen J.F. Reilly	National Semiconductor Rome Labs
Plastic Packages for Memories Used in the Military Environment	V. Verma	Intel Corporation
Plastic Package Availability Program Overview	R. Kovacs	National Semiconductor
Interim Test Results	R. Byrne J. Weintraub	National Semiconductor Corp.
Low Pin Count Environmental Testing	D. Queary	NSWC, Kovacs, National Semiconductor Corp.
Commercial Off-The-Shelf (COTS) Plastic Microcircuits Versus QML38535 Plastic Microcircuits	J.E. Blanton M. Adams A. Thacker	DESC
Specific Issues, Concerns and Solutions Regarding the Use of Commercial Parts	G. Foisey	Foisey and Associates

Appendix B-6: Successful Use of Commercial ICs in Military Systems Symposium Agenda

Presentation Title	Presenter	Affiliation
Plastic Encapsulated Devices in the Boosted Kinetic Energy Penetrator Program	Carol August	Textron
Reliability Environmental Evaluation of Commercial Plastic ICs for Military Applications	Victor Brunamonti	NSWC
Commercialization Study and Test Program	Sun Man Tam	Texas Instruments
Highly Accelerated Stress Testing (HAST)	Briant Hoganson Sam Szymko	United Technologies Hamilton Standard
The Clementine Mission	Mark Johnson	ONR
Signal Processor	Charles Bowers Michael Sicuranza	USAF-ESC DSD
Application of Commercial Plastic SCR in a Military System	Art Mosely	TRACOR
Mission Planning Support Systems Implement Commercial Electronic Components	Don Bently Kari Nilsen	GDE
Commercial and Industrial Components in Military Applications	Bill Ricci	Magnavox
Motorola Commercial Space Parts Program	Tom Cox	Motorola
The Use of High Reliability Industrial Parts for the Commanche Helicopter	Mark Cooper	Litton
The Application of Non-MIL Components to Dual-Use Systems, MODAR-A Successful Case Study	Don E. Wineberg Chuck Hilterbrick	Westinghouse
Examples of Impediments to the Use of PEMs in Military Systems	Michael Pecht	University of Maryland
Programs Prohibiting/Restricting the Use of Commercial ICs	Michael Pecht	University of Maryland
Use of Commercial Integrated Circuits in Military Applications	Fred Jarkels	Army Joint STARS
Military Microwave Landing Systems (MMLSA)	George Youngman	GEC-Marconi
Commercial Bonded (SOI) Analog Technology for Military ASIC's	Pat Begley J. Delgate L. Cohn D. Emily	Harris DNA NSWC
Programmable Digital Radio	Ken Schmidt C.L. Hilterbrick	Westinghouse
A Supplier View of the Use of Commercial ICs in Military Systems	Buf Slay Joe Chapman	Texas Instruments

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VZAP	Electrostatic Discharge Susceptibility Data	$195	$215		
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FMD	Failure Mode/Mechanism Distributions	$100	$120		
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SOAR-2	Practical Statistical Analysis for the Reliability Engineer	$50	$60		
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RMST	Reliability & Maintainability Software Tools	$50	$60		
TEST	Testability Design and Assessment Tools	$50	$60		
RTMG	RAC Thermal Management Guidebook	$75	$85		
NPS	Mechanical Applications in Reliability Engineering *Price Reduced*	$75	$85		
QREF	RAC Quick Reference Guides	$25	$35		
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SOAR-4	Confidence Bounds for System Reliability	$50	$60		
WHDK	New Weibull Handbook	$79	$94		
Reliable Application of Components					
PSAC	Parts Selection, Application and Control	$75	$85		
EOES	EOS/ESD Guidelines	$50	$60		
CAP	Reliable Application of Capacitors	$50	$60		
PEM2	Reliable Application of Plastic Encapsulated Microcircuits	$75	$85		
MCM	Reliable Application of Multichip Modules	$50	$60		
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MFAT-2	GaAs Microcircuit Characterization and Failure Analysis Techniques: A Procedural Guide	$50	$60		
MFAT 1 & 2	Combined set of MFAT-1 and MFAT-2	$100	$120		
QML	Qualified Manufacturer's List: New Device Manufacturing and Procurement Technique	$50	$60		
GAAS	An Assessment of Gallium Arsenide Device Quality and Reliability	$50	$60		
ATH	Analog Testing Handbook	$100	$120		
PRIM	A Primer for DoD Reliability, Maintainability, Safety and Logistics Standards *Price Reduced*	$50	$60		
Quality Improvement					
SPAT	Software Engineering Process Group Handbook	$30	$40		
BPRQ	Business Process Reengineering for Quality Improvement	$75	$85		
TQM	TQM Toolkit	$75	$85		
SOAR-7	A Guide for Implementing Total Quality Management	$75	$85		
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VPRED	VHSIC Reliability Prediction Software	$100	$120		
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